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Designing sustainable faecal sludge treatment systems for small cities in Sub-Saharan Africa

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Declaration

I declare that this thesis has been composed solely by myself, with the support of Professor Martin Crapper, and that it has not been submitted, either in whole or in part, in any previous application for a degree. Except where otherwise acknowledged, the work presented is entirely my own.

Signed

Date

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Abstract

More than 80 per cent of wastewater from human activities is discharged into the rivers or sea without any pollution removal, and the Sustainable Development Goals (SDGs) aim to halve this proportion and increase recycling and reuse globally by 2030. Treatment plants in Sub-Saharan Africa often fail due to lack of operating funds, poor regulation and poor design that does not take into account human factors. The failure of treatment plants can also be put down partly to the funding structures for management, which are often dependent on the disposal tariffs charged. Without sufficient regulation and enforcement, which is often lacking in Sub-Saharan Africa, this often leads to illegal disposal of faecal sludge. Due to the nutrient content and energy potential of wastewater, there is increasing focus on re-use of faecal sludge in ways that can contribute funds for maintenance and incentivise good management of treatment facilities.

This research investigates potential designs for the re-use of faecal sludge in small cities in Sub-Saharan Africa to ensure proper treatment. Conducting two case studies using qualitative and quantitative methods, the research looks at the potential for re-use to be scaled up in Sunyani, Ghana and Mzuzu, Malawi, and whether different designs can ensure good management.

Building upon the research investigation into how previous designs have failed in case studies, the research also investigates the use of agent-based modelling (ABM) as a modelling approach to explore social and technical aspects of sanitation systems to predict how different designs and management approaches can work.

In Sunyani, biogas was the most acceptable option to customers whilst also providing a good business model to fund faecal sludge treatment, either as a decentralised system at public toilets where the fresh sludge is better for biogas production, or centrally at the existing disposal site. The success of biogas as a model that can fund maintenance and ensure good management would depend on the faecal sludge quality of public toilet sludge in the city and the investment level required and how any operating approach would work between the government and private sector.

In Mzuzu, two main approaches to faecal sludge re-use exist currently: the implementation of Skyloos as above ground household toilets which provide compost, and a central disposal site from which compost is illegally harvested. At

disposal, farmers remove sludge from the ponds and apply it untreated directly onto agricultural land. At times, private sector emptying services do not use the ponds, but also apply untreated sludge to agricultural land.

Skyloos were found to have varying levels of success from different Non-Governmental Organisation (NGO) projects, with key sustainability issues being the availability of financing mechanisms, management between landlords and tenants and the trust of and engagement with implementing organisations. Existing approaches to waste management and re-use were found to be inaccessible and not working when implemented for the poorest and people with disabilities. Adopting re-use of faecal sludge in agriculture in Malawi would require improved marketing of sanitation options, financing options for households to incentivize adopting the technology, not targeting to poorest households and people with disabilities, and an improved management model for the treatment site to ensure safe disposal and production of compost.

Looking at ABM as a way of modelling faecal sludge treatment systems in Sub-Saharan Africa, two models of different approaches in Mzuzu were developed to look at scaling up Skyloo toilets and managing the treatment plant. Both models demonstrate the potential of ABM to incorporate social and technical aspects into predicting the performance of different designs and approaches. The success and use of modelling depends on the quality of data that can be collected before implementing system approaches.

Overall the thesis presents different models of treatment and re-use that can work and contribute to operating and maintenance of systems. It is unlikely that any design system will be so profitable that the treatment and re-use of sludge will be able to ensure good management without regulation, so the success of designs depends on relationships between the government and private sector and households in small cities.

Lay Summary

More than 80 per cent of wastewater from human activities is discharged into the rivers or sea without any pollution removal, and the Sustainable Development Goals (SDGs) aim to halve this proportion and increase recycling and reuse globally by 2030. Treatment of toilet waste in Sub-Saharan Africa often fails due to lack of operating funds, poor regulation and poor design that does not take into account human factors. The failure of treatment plants can also be put down partly to the funding structures for management, which are often dependent on the charging fees for waste disposal. Without sufficient regulation and enforcement, which is often lacking in Sub-Saharan Africa, this often leads to illegal disposal of faecal sludge by private sector companies. Due to the nutrient content and energy potential of toilet waste, there is increasing focus on re-use of toilet waste in ways that can contribute funds for maintenance and incentivise good management of treatment facilities.

This research investigates potential designs for the re-use of toilet waste in small cities in Sub-Saharan Africa to ensure proper treatment. Conducting two case studies using interviews and other research methods, the research looks at the potential for re-use to be scaled up in Sunyani, Ghana and Mzuzu, Malawi, and whether different designs can ensure good management.

Building upon the research investigation into how previous designs have failed in case studies, the research also investigates the use of agent-based modelling (ABM) as a modelling approach to explore social and technical aspects of sanitation systems to predict how different designs and management approaches can work.

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Contents

Abbreviations

ABM- Agent-Based Modelling

BDS- Business Development Services

BOP- Bottom of Pyramid

BPD- Building Partnerships for Development

COD- Chemical Oxygen Demand

DFID- Department for International Development

FSM- Faecal Sludge Management

GAMA- Greater Accra Municipality Area

GWC- Ghana Water Company

MDGs- Millenium Development Goals

NGO- Non-Governmental Organisation

PDI- Power Distance Index

SDGs- Sustainable Development Goals

SOIL- Sustainable Organic Integrated Livelihoods

SSA- Sub-Saharan Africa

SSIPs- Small Scale Independent Providers

SWE- Small Water Enterprises

UDTs- Urine Diverting Toilets

UN- United Nations

WEDC- Water, Engineering and Development Centre

WHO- World Health Organisation

WSPs- Waste Stabilisation Ponds

WSUP- Water and Sanitation for the Urban Poor

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1 Introduction

This thesis presents a social research into designing sustainable faecal sludge treatment systems for small cities in Sub-Saharan Africa (SSA).

The Millennium Development Goals (MDGs) were focused on household sanitation with the aim of halving the proportion of people without improved household sanitation between 1990 and 2015. Improved household sanitation is defined as a facility that hygienically separates excreta from human contact and is not shared with other households. This goal was not achieved with 2.4 billion people still lacking access to improved sanitation and 946 million still practicing open defecation (WHO / Unicef JMP, 2015). There were many challenges identified to achieving the MDGs on sanitation in Africa by Danida (2010), shown in Table 1-1. As well as these challenges there are also technological challenges such as lack of space for sanitation facilities and difficulties of transporting faecal sludge from on-site systems (Chowdhry & Kone, 2012; Mazeau, 2013). The new Sustainable Development Goals (SDGs) aim to fully end open defecation and achieve access to adequate and equitable sanitation and hygiene for all by 2030 (UN, 2015), though the same challenges are likely to remain for achieving these.

Political Barriers	Economic Barriers	Social Barriers	Monitoring Barriers
• Lack of political commitment	• Limited economic growth and restricted social development • Lack of funds • Inappropriate use of funds • Insufficient private sector involvement • Lack of Demand	• Choice of appropriate technologies linked to lack of demand	• Actual choice of measurement focuses on coverage of technologies rather than usage and functionality

Table 1-1: Framework of barriers and issues for MDGs in Sub-Saharan Africa

Focusing on the treatment of waste from sanitation systems, more than 80 per cent of wastewater from human activities is discharged into the rivers or sea without any pollution removal, and the SDGs aim to halve this proportion and increase recycling and reuse globally (UN, 2015). Whilst the global goals use the broader term of

wastewater which can refer to industrial waste, sewered waste or household waste, in SSA on-site sanitation systems produce faecal sludge. One of the main challenges in operating faecal sludge treatment systems is the lack of funds to operate and maintain systems even when they are relatively simple (Danida, 2010). The production and sale of resources as a business from treatment could contribute to the effective funding and management of faecal sludge treatment (Diener, et al., 2014). This research hypothesises that faecal sludge treatment systems that recover value from the waste can combat the political and economic barriers identified in Table 1-1 in the following ways:

- Profitable business models linked to sustainable treatment and re-use of waste would have less need for political regulation that is often lacking
- Resource recovery would provide funds that are currently lacking for maintenance and operation of systems
- Resource recovery models would stimulate demand for private sector involvement in the sanitation sector by providing profitable business models
- Resource recovery would stimulate demand for faecal sludge across the sanitation chain by identifying a value proposition in treating and re-using the end product

Based on this the overall aim of this research is to investigate **whether resource recovery as a business can ensure effective management of faecal sludge treatment systems in Sub-Saharan Africa.** This research mainly intends to reduce the economic and political barriers identified in Table 1-1, but it must also account for the social barriers and issues to be successful. The work is intended to be of interest to:

- Policy makers
- Donors and financing organisations for development projects in SSA
- Development practitioners
- Businesses in sanitation in SSA

The thesis is structured into four sections: literature review, methodology, results and conclusions. The literature review section covers an extensive review of literature on the subject of urban sanitation, particularly focusing on wastewater and faecal sludge treatment, as a business. Literature is reviewed along the framework of barriers identified by Danida (2010) of social, political and economic factors with a section also added to look at technical issues. Along with the review of academic

literature and ‘grey’ literature from NGO interviews and informal conversations were conducted with people who worked on sanitation projects to understand the challenges further. Having identified the gaps in the existing knowledge around sanitation the research question of ‘Can resource recovery ensure effective operation of faecal sludge treatment?’ is broken down into smaller research questions and objectives. Section 3 then covers the methodology for answering these questions. Section 4 presents the results from the case study in Sunyani, Ghana and section 5 presents the Mzuzu, Malawi case study results. Section 6 compares the two case studies before section 7 explores agent-based modelling (ABM) of future systems. Section 8 reflects and concludes upon the entire research.

2 Literature Review

2.1 Section Structure

This literature review is aimed at understanding the technical, social and economic environment for sanitation in Sub-Saharan Africa. To do this the research consulted academic literature, grey literature from NGOs and conducted informal conversations with stakeholders in sanitation. Section 2.2 looks at common technical challenges identified across Sub-Saharan Africa with sanitation infrastructure and the implications this has for safely disposing and treating excreta. Then section 2.3 looks at the sanitation infrastructure more specifically in the countries Malawi and Ghana, where the researcher has local links for conducting fieldwork. Moving beyond this initial technical assessment of the situation for sanitation the research looks to assess which potential options could be implemented instead for faecal sludge or excreta treatment, and the challenges and experiences with implementing them in section 2.4. Section 2.5 looks at the challenges and environment that different businesses operate in for providing sanitation services across Sub-Saharan Africa. From this the gaps in the literature are identified in section 2.6 to define the research objectives to be answered by the PhD research.

2.2 Challenges in Urban Sanitation across Sub-Saharan Africa

Most urban populations across Sub-Saharan Africa are not served by sewer systems for sanitation (Peal, et al., 2015) due to their expense and instead they rely on on-site sanitation systems (Schaub-Jones, 2012; Kone & Strauss, 2004), as depicted in Figure 2-1. This system relies on household sanitation where excreta is stored either in pits or septic tanks, and then transported by trucks or other vehicles to a treatment point, where it can then possibly be re-used to harness the inherent value of the excreta.

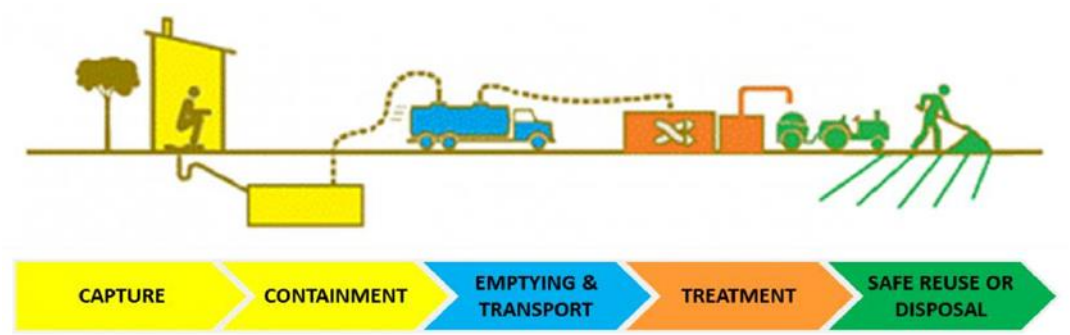

Figure 2-1: Faecal Sludge Management Chain (Stanford, 2015)

2.2.1 Capture and Containment

One of the largest challenges with people accessing improved household sanitation in urban areas is simply a lack of space. Often as populations expand the space in compound accommodation or slum areas has driven rooms to be converted for renting instead (Mazeau, et al., 2014). This was also found in literature looking at the decision process in adopting change to household sanitation where space was again found to be a large barrier to installing improved household facilities (Obika, et al., 2002; Jenkins & Scott, 2007). Jenkins and Scott (2007) also identified tenure issues, lack of available builders or savings and competing priorities as limiting for households even though they associated improved sanitation with cleanliness and hygiene.

Another large challenge at the household level of sanitation depends on the soil conditions in which latrines are being installed. A particular risk is that if there is a high water table then simple pit latrines can lead to groundwater contamination (Graham & Polizzotto, 2013; Krishnan, 2011), and can overflow into the surrounding environment if they are not emptied regularly (Hounkpe, et al., 2014).

A final difficulty with the dominant use of the pit latrines is the state of the excreta when the latrines need emptying (Strande, et al., 2014). Often in the case of vacuum emptying, there can be a build-up of solid waste that can choke the mechanism and require ‘fishing’ to separate the solid waste out manually. Looking further down the chain the large range of retention times that exist in toilets lead to a material of varying quality which can make designing a system to treat waste/harness value more complicated (Strande, et al., 2014).

There are several sanitation businesses aiming to solve some of these challenges by providing mobile toilets with small storage and regular collection assessed in a

report for DFID (Hystra, 2014). These toilets have reduced space requirements, do not require fixed infrastructure and are entirely above ground and the regular emptying of cartridges, as is done in these businesses, allows a more uniform understanding of the properties of the waste required to be treated.

2.2.2 Collection/Transport

According to Trémolet's (2013) literature review of the field of sanitation economics and market failures, a large failure in on-site sanitation provision comes at the transport stage of the chain with services considered to be inadequate. The issue of transport in urban sanitation is large with the cost of transport and distance to treatment centres acting as constraints to businesses and entrepreneurs safely disposing waste (Schaub-Jones, 2012; Kome, 2011). Chowdhry and Kone (2012) investigated financial data of faecal sludge operators across 30 cities in 10 countries in Asia and Africa to look at the business environment. Whilst the study does not specifically look at Ghana or Malawi and focuses mostly on cities of a larger population (more than 500,000 people) it still provides a large dataset from a consistent methodology with all providers to give trends in viability and profitability of sanitation of a business. They found the weight of faecal sludge acts as a technical challenge in sludge disposal as the depreciation of trucks over time hits the ability of transport businesses to make a profit. Initial assessments of profitability found African transport businesses to be more profitable than Asian but after factoring in depreciation costs were actually less profitable. This issue was also cited in informal conversations with Clean Team Ghana that had chosen to use a tractor and trailer instead of a truck to ensure longevity of the vehicles that are the main capital outlay for transport businesses. A further challenge to the transport and collection of faecal sludge in poor urban areas is that the densely packed, unplanned buildings and narrow roads make it hard to access with vehicles, meaning that manual collection may be more suitable. This issue was found in Kampala, where Murungi and van Dijk (2014) conducted semi-structured interviews in an area of the city. Kampala is a capital city with a large population and densely planned areas, though this issue may be reduced in smaller cities of Ghana and Malawi. In Chowdhry and Kone's (2012) business analysis of FSM they found that manual emptiers either empty waste in nearby lands or open drains, with local cheap transport used if needed to carry a long distance.

One potential option for improving transport is the use of transfer stations at the edge of the 'slum' area where manual emptiers bring waste, which is then collected by trucks and taken to treatment works (Tilley, et al., 2014; Strande, et al., 2014). Another form of the transfer station can work through directly connecting to a gravity sewer which takes the waste to the treatment plant, however both options require expert construction (Tilley, et al., 2014). From informal discussions, there can also be difficulties with getting land tenure to build transfer stations and further difficulties with the ownership of the infrastructure provided. A large business may be able to build and take ownership of the infrastructure and the land; however there may be a requirement in the current sanitation market for this to be provided by government. Another potential solution to the large challenges in collecting and transporting waste is the use of smaller, decentralised treatment systems, which is cited as a potential way to keep costs of sanitation provision low (Trémolet, 2012). These can provide effective and safe disposal, or re-use, of faecal sludge whilst reducing the transport requirements associated with cities like Kumasi where there is only one treatment plant to dispose waste (MLGRD, 2010).

2.2.3 Treatment

More than 80 per cent of wastewater from human activities is discharged into the rivers or sea without any pollution removal, and the SDGs aim to halve this proportion and increase recycling and reuse globally (UN, 2015). One of the main challenges in operating treatment is the lack of funds to operate and maintain systems even when they are relatively simple (Danida, 2010). Research looking at treatment management in Cotonou, Benin, found that under private management the treatment plant was receiving 2.65 times the design capacity (Hounkpe, et al., 2014), with unsafe levels of COD being discharged into the sea. This can also be put down partly to the funding structures for management, which are often dependent on the disposal tariffs charged. Arguments often favour either pursuing cost recovery to ensure maintenance of systems, or they can argue the opposite that these tariffs would simply encourage illegal dumping (Schaub-Jones, 2012). Here the use of smaller, decentralised systems could be a potential option to reduce the issues for companies that are disposing to make sure that waste is disposed safely (Trémolet, 2013). There are a series of different decentralised treatment options that are established with the potential for re-use to recover value from the waste (Tilley, et al., 2014) , which could reduce the issues around maintenance by providing another income stream for management.

2.3 What is existing sanitation availability from Macro to Meso to Micro scale?

2.3.1 Country Scale- Ghana and Malawi

There is a significant level of literature to consult when looking for the sanitation situation at a macro scale in African countries, particularly in the aspects of sanitation that were covered by the MDGs. Figure 2-2 shows the progress of Malawi and Ghana towards the MDGs, with 53 and 80 per cent of the population respectively relying on unimproved and shared sanitation.

Looking at urban sanitation, the public toilet is the most common facility for the urban poor in Ghana (MLGRD, 2010). 73% of urban dwellers do not have private sanitation facilities, and instead they rely on shared toilets or an informal network (Mazeau, 2013). One challenge of shared facilities is that under the Millennium Development Goals shared facilities did not count as 'improved' facilities which can discourage investment in these facilities (Mazeau, 2013). This is also the case for the new sustainable development goals where shared sanitation is classified as limited sanitation which in dense areas means providing improved sanitation may be difficult for investment from donors when it may be the only option in dense settlements (Evans, et al., 2017).

In terms of moving from household facilities to safe disposal and treatment in Ghana the infrastructure is poor. Only a minor share of faecal sludge and wastewater in Ghana is properly treated (Obuobie, et al., 2006). This is also covered by the Ghanaian government's own sanitation plan which states that 'treatment of wastewater in all regions is very abysmal' (MLGRD, 2010), with only 7 of the 44 treatment plants in the country functioning adequately.

In Malawi 33% of the population relies on either unimproved sanitation facilities or practices open defecation (WHO / Unicef JMP, 2015). In urban populations the proportion of people using improved facilities is larger as shown in Figure 2-2. Increasing urbanisation and limited property space in Malawi makes the emptying of pit latrines, the most common form of sanitation facility, an increasing option for households (Chunga, et al., 2016; Chirwa, et al., 2017).

From informal conversations with people working in the major cities of Malawi the state of treatment is also poor with most treatment plants non-operational across the country.

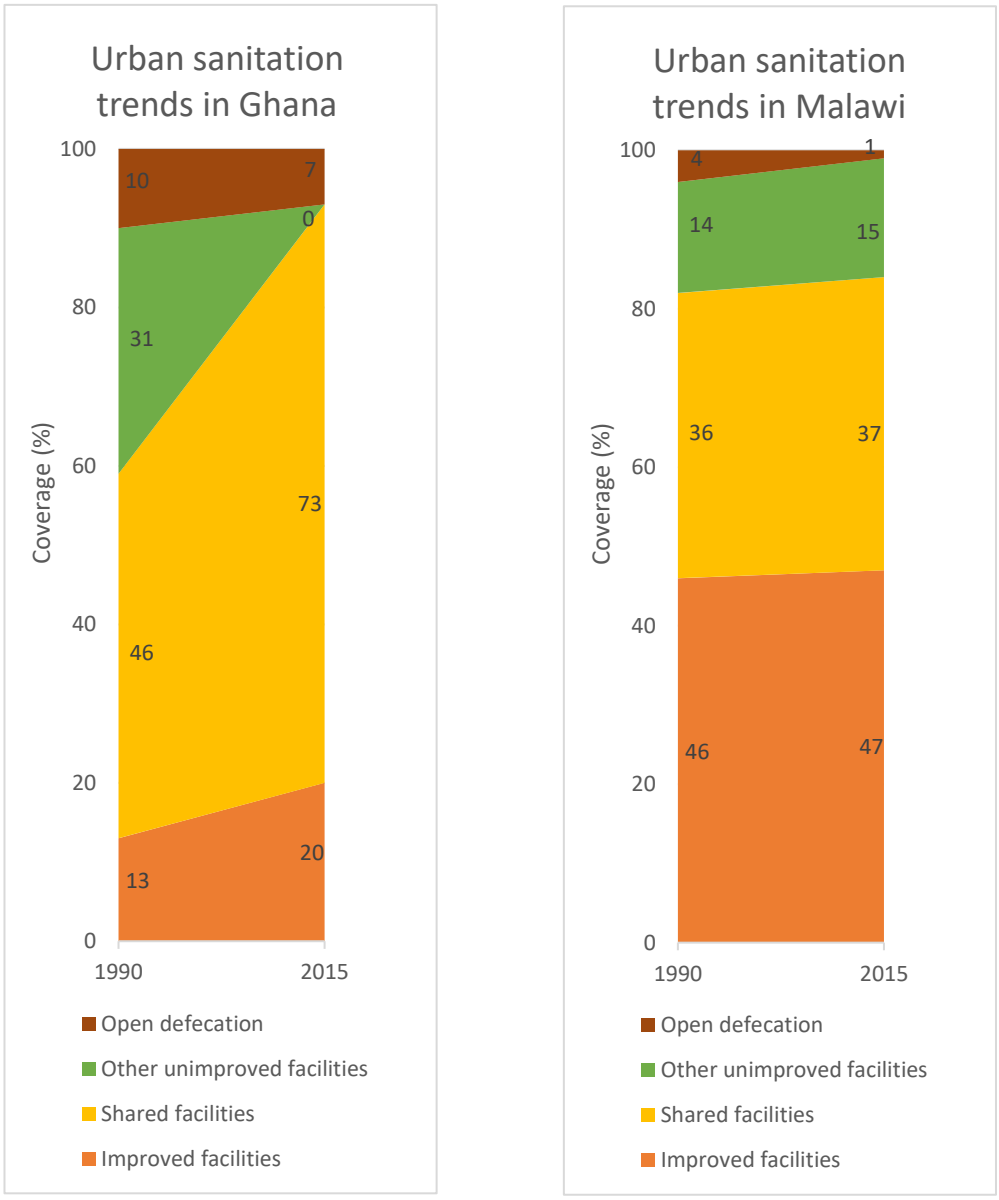

Figure 2-2: Percentage Distribution of Toilet Facilities in Ghana and Malawi (WHO/Unicef JMP, 2015)

2.3.2 City Scale

Looking at specific cities in Ghana, there is literature available to give an idea of the sanitation situation at a meso scale in different cities. Accra, the capital, has a wealth of literature covering it with Adank (2011) providing an overview of the sanitation infrastructure in Greater Accra Municipality Area (GAMA). A summary diagram is also made assessing the different providers at each stage of the chain, shown in Figure 2-3. The report identified two different treatment plants managed by the municipality which were designed to have a combined capacity of 36,000m^3/day but only treat around 6,500m^3/d. The study found that there were also 35

independent treatment plants but that only four were still functioning. Looking at the management of faecal sludge in Accra, there are three different plants which were all not functional leading to the waste being dumped in nearby streams or on the seashore (Adank, et al., 2011). A more recent study in Accra found that there are still no operational faecal sludge or wastewater treatment plants, with no accurate estimate for the volume of faecal sludge produced available (Diener, et al., 2014). Waste Stabilisation Ponds (WSPs) are a widespread treatment facility in urban Ghana, where all the government facilities are WSPs in Kumasi (Tenkorang, et al., 2012).

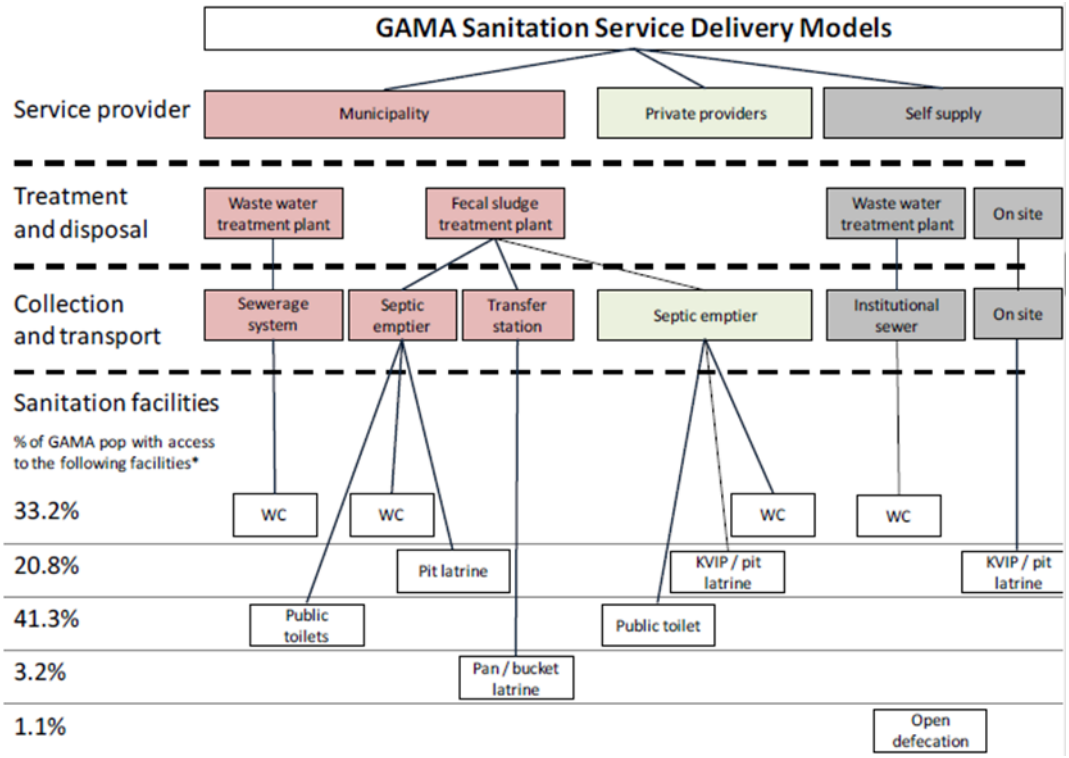

Figure 2-3: Sanitation Service Delivery in Greater Accra Metropolitan Area (Adank, et al., 2011)

In Malawi there is less literature covering overall treatment capacity, but overall services in Mzuzu and Blantyre are reported to be broken down from informal conversations. In Mzuzu a paper looking at FSM found that there was limited legislation and enforcement for sanitation, and that the specified treatment points were usually empty (Nyirenda & Holm, 2015), with farmers often paying emptying companies to discharge on their gardens instead. Illegal disposal and reuse by people in surrounding urban areas are practiced (Chiposa, et al., 2017).

2.4 Technical Options for Treatment Stage of Sanitation with Resource Recovery

There are a series of technical options that can be implemented to reuse faecal sludge or excreta, which are suitable for varying different contexts (Tilley, et al., 2014). Often a key determinant of the suitability of different resource options will be the type of technologies that exist upstream in the FSM chain. This section of the literature review looks at different potential options for recovering value from faecal sludge or excreta and examples of them being implemented.

2.4.1 Biogas

Biogas is a mix of methane, carbon dioxide and other trace gases that can be used in a similar way to other cooking fuels (Tilley, et al., 2014). It can be used to generate electricity or directly burned for cooking (Ingle, et al., 2012). Biogas cannot be used with existing gas appliances as they need less air for combustion.

A few different papers have looked at the potential for biogas to be generated as a way of recovering value from waste treatment. Due to the difficulties in compressing, storing and transporting biogas (Kapdi, et al., 2005), it is best if any technical solution based on biogas production has the end-user as close to the source of biogas as possible (Tilley, et al., 2014). One model of this was attempted where biogas digesters were used at a public toilet. Here the biogas was directly connected to a café that cooked for 50 people a day, with plans to enter a contract with the café for 10-15 euros a month. This is practically insignificant in the scheme of the average total operation costs which were 7,012 euros a month (Rieck & Onyango, 2010). There is also the possibility to generate extra value from the remaining slurry from the biogas digesting process by using it for composting (Diener, et al., 2014).

As well as the potential for biogas to be produced from digesters, there are also research papers that look at the potential for anaerobic ponds in Waste Stabilisation Pond (WSP) systems to be covered and the biogas from the anaerobic digestion process to be used (Heubeck & Craggs, 2010). In Burkina Faso this possibility was studied with mean production rates of 121 litres $m^{-2}d^{-1}$ (Konate, et al., 2013), which potentially raises the prospective of retrofitting Biogas production systems to the anaerobic ponds of WSPs that are common across Sub-Saharan Africa (Shilton, 2005).

2.4.2 Fuel

There has been established use of faeces as fuel, particularly in the use of animal fuel (Henuk & Dingle, 2003), with evidence of the use of cow dung as fuel as early as 2500BC in Egypt (Bard, 2015). There are now different modern projects looking at using faecal sludge across Sub-Saharan Africa, with a Bill Gates Project in Senegal working with an omniprocessor that burns fuel to generate electricity and water (Gates, 2015). The possible use of dried faeces as fuel was also investigated by two comparative studies of potential resource recovery models (Diener, et al., 2014; Murray, et al., 2011). There is currently a business operating in Rwanda aiming to dry faecal sludge so that it can be sold as fuel to industry (Pivot, 2016). It is in the early stages so the economic side of the technology is not clear but as a system it is a relatively simple system to operate and can generate a valuable product.

2.4.3 Aquaculture- Fish Rearing

In pond treatment systems, it is possible to rear fish on the nutrients in the water and the algae and other organisms (Tilley, et al., 2014; Tenkorang, et al., 2012), saving money on traditional fish feed that is used in fresh water aquaculture systems. Different studies have looked at implementing fish rearing systems in Sub-Saharan Africa. One of the main issues is with selecting fish that can survive the often-low oxygen levels that exist in aerobic ponds at the end of WSPs (Waste Enterprisers, 2012). Another issue that can often arise is cannibalism among certain species of fish. In the initial pilot project, there were many issues with catfish stocked in the ponds in Kumasi dying which undermines the commercial potential for resource recovery (Tenkorang, et al., 2012). The practice of waste-based fish rearing is more common in Asia, with an integrated duckweed and fish rearing system running an operating profit in Bangladesh (Iqbal, 1999).

2.4.4 Aquaculture- Plants

There are ranges of plants that can be grown with the nutrients present in wastewater or faecal sludge that can be used for animal consumption (Hounkpe Wendeou, et al., 2013). The main example of aquaculture found in literature is the growth of duckweed on the surface of WSPs, which is reviewed for the potentials and possibilities in wastewater treatment by Iqbal (1999). The growth of duckweed also contributes to the treatment of wastewater with the covering surface of plants inhibiting algae growth and thus reducing Total Suspended Solids as opposed to

WSPs. The main technical constraints to growth of duckweed are shortages of nutrients in water, algal blooms caused by light penetration and insect and fungal infestations that can inhibit growth of the plant and therefore the economic revenues and treatment efficiency. Often a defining constraint in the suitability of aquaculture systems will be availability of land as duckweed can grow in shallow ponds of up to 1000m^2 surface on the faecal matter and urine of 29-50 people so a treatment system for a city would require large areas of land.

2.4.5 Agriculture

Fertiliser production or composting is a quite widespread method of resource recovery from treatment with a long history of use stretching back to Romans, Greeks and early Chinese societies (Mariwah & Drangert, 2011). The use of excreta for agriculture varies from untreated sludge application to by-products from anaerobic digestion or pelleted sanitised end products (Strande, et al., 2014). This can take varying forms from the application of raw faecal sludge (Nyirenda & Holm, 2015) or dried faecal sludge (Diener, et al., 2014) to the production of pelleted, fully treated products (Cofie & Nikiema, 2015). Another initiative began with producing fertiliser in Ethekwini area of Durban, using a mobile composting LaDePa (latrine dehydration and pasteurisation) machine that produces a sanitised low grade fertiliser (Harrison & Wilson, n.d.).

As well as more centralised collect, treat and distribute models of fertiliser or soil amendment production, different household facilities can produce decentralised products (Tilley, et al., 2014). A case study looked at implementing Urine Diverting Toilets (UDTs) in Benin (Dubois, 2014). At this stage, the experiences using the compost at the demonstration site are only qualitative and limited to observations from farmers of:

- Less watering
- Better growth
- No need for chemical fertilisers
- No need for insecticide/fungicide
- No erosion issues

In rural and peri-urban settings, arborloos can be used to utilise the nutrients from pit latrines to grow trees when they become full (Tilley, et al., 2014). This is based on abandoning latrines when they become full, which means that space is a big

requirement to abandon latrines and grow trees on a regular basis which may be more suitable in rural areas. There are other household based such as ecosan toilets that are designed to be emptied so that the excreta can be used as soil amendment (Chunga, et al., 2016).

2.4.6 Social Acceptability of Resource Based Treatment Models

Beyond the technical feasibility of any treatment system the social context that systems are being designed for needs to be considered, as if a resource such as fertiliser or aquaculture-based plants is unacceptable to people then there is no demand and therefore no revenue to fund treatment. This can vary a lot depending on what the end-use product would be and how people would interact with it. For instance, a biogas-to-electricity plant is not going to involve any customers coming into contact with faeces, whereas composting relies on farmers being willing to handle treated faeces. There are some papers that have looked at the potential acceptability of different resources in different contexts, though it is hard to apply any local cultural concerns to larger areas as they can vary so much. For example, two studies in different areas of Ghana found diametrically opposed opinions on the use of human excreta in agriculture, with one study finding a generally negative attitude towards the idea (Mariwah & Drangert, 2011) and another finding a majority acceptance of the idea (Danso, et al., 2006). This could either be revealing local differences within the country or a result of two different methodologies finding different answers. Another study in Madagascar found relatively open attitudes to fertiliser from vermicompost but overall a need to try the product and see before they could adopt it (Zetek, 2013). Another study looking at the acceptability of waste-reared fish in Ghana found many people, 44% of those surveyed would reject sewage cultured fish due to perceived health hazards (Abdul-Rahaman, et al., 2012).

The literature surrounding the social acceptability of different resources generated from waste treatment in Sub Saharan Africa is limited, however the papers found demonstrate the importance of understanding local cultural context for the suitability of different treatment models as much as the technical feasibility.

2.5 Market Environment for Sanitation across Sub-Saharan Africa

This section looks at the existing market environment for different approaches to providing sanitation across Sub-Saharan Africa. There is a large range of scales that sanitation provision as a business can be operated, from large national or even multi-national companies to Small Scale Independent Providers (SSIPs). This section will assess the environment for different scales of providers to understand how the challenges vary from small providers to businesses and what implications this would have for operating treatment as a business.

2.5.1 Business Models in Urban Sanitation

This research has identified two major sources of literature which review new innovative business models for on-site sanitation businesses in developing countries. Hystra (2014) created a report in September 2014 assessing case studies and business models of nineteen different sanitation social enterprises. This is an independent report assessing different businesses funded by the departments for international development in UK and France, so is a reliable assessment of different business models. The report mainly focuses on mobile home toilets with a regular collection service in urban areas.

Another report created by a coalition of different large NGOs and organisations provided a catalogue of different sanitation businesses looking for funding or support at a Bottom of Pyramid Convention (IRC, et al., 2014). As this is a convention where businesses were looking for funding or partners the objective is to sell and not to inform so some of the challenges may not be presented here. The paper still provides an example of different sanitation businesses and the models they operate in different contexts though. To fully review different challenges and business models across urban sanitation informal conversations were conducted with sanitation works with the objectives of finding business models not yet in published literature and finding more of the challenges that are experienced.

This section gives a description of the different businesses found both in these sources of literature across further literature review and from informal conversations with sanitation NGOs. The section investigates the innovative elements of their respective models and how they could change aspects of the urban sanitation chain as it exists in SSA now.

2.5.1.1 User Interface

Providing toilets at the user interface stage of the sanitation chain was the most common type of business found across the two different catalogues of sanitation businesses. There are ten different enterprises in the two reports operating in providing toilet products.

Appsani is a business registered in Indonesia looking to provide customers with a one-off sale of a toilet and septic tank product. The design is standardised and sold through a network of 120 entrepreneurs in rural areas that are trained by the enterprise. The elements of Appsani's business model that are innovative and interesting is the direct engagement with entrepreneurs selling the product, as a method of providing business skills to entrepreneurs which is cited as a barrier to sanitation development in the world bank report on the potential of sanitation markets in the developing world (Sy, et al., 2014). Setting up a sanitation enterprise that also provides Business Development Services (BDS) to entrepreneurs would require a very skilled management team with experience in business to provide training.

Banga Building, in Bangladesh, is another enterprise providing a standardised toilet design, which was designed by iDE and is manufactured by a major Bangladeshi latrine manufacturer which has positive implications for scaling up production. The product design of a SanBox is a combination of a toilet and storage product for users in a compact box. The use of a smaller storage system combined with a toilet is a product innovation also done by other sanitation enterprises, however other enterprises provide the toilets as part of a service based business model including collection and transport of waste. The main benefits of smaller toilets instead of pit latrines are that they are easier to empty and transport waste (Schaub-Jones, 2010). The requirement for frequent emptying can also have benefits for both the user of the toilets and the business providing the service, as the demand for emptying latrines can be irregular making it a less reliable source of income (Gero, et al., 2013). This can have a large impact where large capital investments in emptying equipment are made but can then lie unused (Schaub-Jones, 2012; Sugden, 2013a). There are instances where people in low income areas cannot afford to empty the latrines when they are full as they are a one-off cost and saving is not an option, so the staggered small payments model could be more suitable to serving the poor (Hystra, 2014).

Silafrica is a product-based toilet business run by a company already making plastic products in Mauritius developing movable plastic toilet slabs that can be upgraded from an existing pit latrine or built in a new pit latrine. This business model has the ability to improve the experience of using pit latrines for people in low income areas, which may help to improve low demand which often acts as a bottleneck to sanitation provision (Sy, et al., 2014). Demand promotion is considered to be vital for providing improved sanitation (Trémolet, 2012), so providing improved products for users could be an important way of improving sanitation in low income areas.

SuSan design is looking to provide its own design products in Kampala and Nampula in 2015, with the products including a unisex urinal and faecal sludge treatment units. The business model includes the community and entrepreneurs in the provision of collection, treatment and sale of urine as fertiliser. The product provides innovation in using unisex urinals which provides accessibility to both genders. The resale of products as fertiliser also provides another source of revenue beyond direct charges for poor people using sanitation, potentially making the products more affordable.

TEECS is a business with a sanitation solutions branch to provide modular latrines, SaTo pans, pit emptying services and sanitation finance and business development.

Banka Bioloo provides bio-toilets and bio-tank products to different segments of the market in India. These are a combined solution with a toilet and tank system being serviced with a bacteria liquid produced by Banka to digest the waste. The system has been adapted and sold to Indian Railways with 500 tanks and 100 tanks have been sold to household levels. These are mainly sold to wealthier clients including businesses and NGOs due to the high cost of the technology. The model of selling combined toilets and bacteria for digesting the waste provides a solution to the transport of waste, a service which is very poor in on site sanitation (Trémolet, 2013).

Biofilcom is another enterprise that provides toilet products, with the products coming combined with organic digester to reduce the waste volume and a water seal to reduce odour. The system comes with a toilet, tank, wash basin and shelter for approximately USD1,000 (Hystra, 2014), making it an expensive investment. The tank alone costs USD390 and utilises tiger worms, black soldier flies, beetles and cockroaches to process the waste providing a volume reduction of 90%. This system provides a reduced odour for users which is commonly cited as a key

problem with toilets for users (Hystra, 2014). The system also provides a large reduction in volume of waste which would reduce the burden on transport services for waste, and it could potentially provide adequate treatment for the soil effluent mitigating the need for centralised treatment and transport. Further tests are needed to prove this system can provide adequate treatment. The existing model is also expensive and the business model looks to serve middle-class clients as an alternative to septic tanks, so the business model would have to be adapted to serve poorer people.

Mohan Rail Components is another sanitation enterprise in India producing bio-digester systems for trains. The company is also producing models designed for households, however only 50 have been sold privately with the main sales from a planning commission contract, not the users and households. This shows that the pricing model and design may not be suitable to provide sanitation in low income areas in Sub-Saharan Africa as it has only really succeeded through government contracts.

Stone Biotech is another company in India that has diversified from serving the railway systems into sanitation. The company produced an aerobic digester toilet with a bacteria refill to digest waste. Approximately a thousand toilets have been installed with around 50% from households, again partly funded through grant support from governments and other organisations.

A new technology looking to enter the market is the Tiger Toilet design that is being piloted in Myanmar, Uganda and India. Tests with Black Soldier Fly larvae found that the pathogen Salmonella and other viruses were reduced with this treatment whilst also improving the nutrient content of the waste (Lalander, et al., 2014). This toilet again uses a water seal to avoid odours, and the biological breakdown from tiger worms provides a solid reduction of 80% to 90% of solids. The two outputs of the system are vermicompost from digestion and treated effluent from a drainage layer that is safe to discharge into soil. These toilets are again innovative as a solution in using on site treatment to avoid the need for transport to centralised treatment systems, and the production of vermicompost which will have a resale value to mitigate the costs of the technology.

There are a series of businesses that have been shown to work in producing toilet products that treat the waste directly, which removes the huge sanitation challenge of transport and centralised treatment systems but brings in a challenge in that they

are expensive with toilets costing between USD150 and USD1,000 to install. These have had some success in replacing septic tanks for middle class, but are unlikely to reach the poorest areas, as even flexible funding would require a large capital to fund the production whilst waiting for staggered repayments.

There have been issues found in the ability of sanitation businesses to become viable through only providing one-off products as demand wanes after installing a singular toilet (Mulumba, et al., 2014), which is a concern for models orientated around providing a singular product with no follow up service.

Latrine products are considered the easiest method of providing sanitation as a sustainable business, and this can be partly seen in the diversity of different product models that were discussed in the interviews. At the most basic level toilet products involve simple attachments to existing latrines that can make the experience more pleasant for customers. The gooseneck pan and flapper, discussed with two different interviewees who had worked in NGOs supported businesses in sanitation, are attachments to pit latrines to reduce odours and vectors. The flapper uses a simple counter weight mechanism that would seal the latrine when not in use and empty into the pit after use, removing pathways for vectors and preventing odours. The gooseneck pan uses a cup attachment on a ceramic pan making a u-bend into another pipe that then empties into a latrine, this allows a seal to be made again reducing odours. A ceramic pan business was also attempted but ran into challenges with importing due to taxes.

A more advanced business model for a full superstructure and latrine product was the Durasan, discussed with a sanitation consultant from an NGO. The main innovation in the Durasan was the ability for it to be simply assembled and taken apart as opposed to most toilets that are fixed infrastructure. This allowed an easier customer access to finance the purchase, as the loan could be secured against the value of the toilet that could then be taken down if payments are not made.

An element of latrine products not currently being developed but mentioned in the interview is looking and interacting more at the latrine stage of FSM, which could potentially increase efficiency. Looking at the possible design changes that could be implemented in pit latrines could effectively reduce the filling rates of latrines making them much more sustainable in the long term. The flip side of this model is that it may actually hurt the market for pit emptiers with demand for emptying becoming sparser and more sporadic, exacerbating an existing constraint on the FSM chain.

2.5.1.2 User Interface, Collection and Transport Businesses

There are a series of businesses in sanitation in low income countries that look to provide a different model of sanitation through providing small toilet systems to build a relationship that is then followed up with collection services regularly.

Banza is a company in Kenya operating this model where waterless, portable toilets are installed in homes without sewage connections. The toilets are leased to people whilst remaining property of Banza, and people are charged for daily service by waste collectors who collect the waste in biodegradable bags and dispose the bags into the sewage line. This model helps to make transport easier as the regular collection reduces the need for heavy infrastructure such as trucks and fuel which are large costs for sanitation providers (Chowdhry & Kone, 2012). The use of leasing to customers as a model for people could be a solution in low income areas where poorer people are unlikely to want to invest in infrastructure, especially if they are only renting their accommodation temporarily. This was found in a study in Kampala where residents who were renting did not want to spend their money on improved sanitation construction as they may move elsewhere (van Dijk, et al., 2014). The project was only at pilot stage at time of writing, with 38 toilets installed in Mathare slums in Nairobi. Another area of interest in the model is the contracted mobile cleaners used, who were part of a micro-enterprise already providing cleaning services such as garbage collection and cleaning. The use of a small toilet with easily removable bags made it easier for the collection service to be provided as part of an existing cleaning business. Clean Team is a social business owned by Water and Sanitation for the Urban Poor (WSUP) in Ghana working on a similar model of leasing toilets for a monthly fee with a collection service. The service orientated model of sanitation again provides regular stable income for a business as opposed to the one-off revenues of toilet building, and occasional latrine emptying services. X-Runner works on a similar model again of renting toilets in slum areas and providing waste collection services in Peru at pilot stage serving 76 households. Sustainable Organic Integrated Livelihoods (SOIL) is another similar model operating in Haiti providing urine diverting toilets that remain the property of SOIL and then following with a collection service twice a week for the waste to be treated and composted and resold. A challenge in the business is the market for compost as only 50% of the compost produced is sold on. These organisations all offer solutions to large transport challenges in sanitation and providing a likeable toilet product that people want to use, however they are all in pilot stage, so the

large challenge and area of interest is whether these models can scale up to serve larger urban populations. To do this there is either a need for different transport systems to transport waste to treatment centres, with manual emptiers taking it to a point where a vehicle will then be used, or more local treatment plants. The success of these businesses is tied into the logistics of collection, with a dense population of people wanting the service required to make a sustainable business. These businesses also require a large capital to tide the business over while the staggered rental payments cover the initial investment of producing the toilets.

Peepoople is a social enterprise operating in providing sanitation in Kibera, an urban slum in Kenya, providing single use self-sanitising bags as an improvement upon open defecation or unhygienic public toilets. This business model again serves people who are majority renters and practice open defecation. The bags are sold individually for 3 Kenyan Shillings (SHK) and SHK 1 is refunded when the bags are returned to collection points. The bags are then transported from containers to a sanitation yard where they are decomposed over 3 to 4 weeks into compost which is then sold to farmers. This solution is an innovative, infrastructure-light approach to sanitation in poor areas and provides resource recovery. Unfortunately, even with projections to bring down costs of production from 15 SHK to 5 SHK there would still need to be sales of 60,000 bags a day to break even showing that the business needs to reach a large scale to become profitable which could be a large challenge. There is also a question as to whether the products are considered attractive by users and whether demand can scale up as required.

Sanergy is a business in Kenya looking at providing full faecal sludge chain services. This involves building toilets that can be operated as franchises either commercially or residentially, with collection services and then treatment. Currently the three resources produced from treatment are energy, animal feed from Black Soldier Fly and fertiliser (Sanergy, 2016).

A couple of interviews were based on discussions about toilet businesses that moved on from latrines but also had a collection service integrated. The first was a business model leasing UDDTs as public toilets to local businesspeople and then running a collection service which then processed the waste for fertiliser. The interesting element in this model is that the charge for leasing also includes training and BDS helping to develop the business skills that are often cited as lacking. Another business was based on a mobile toilet and collection service with regular

collection of cartridges instead of the irregular latrines. This model was based on subscription rather than up front funding giving better access to low income customers. The distinguishing features of this model that were interesting was the use of human centred design to identify the product and service model and then the ability to recruit highly skilled business people to the business which was cited as fundamental to the business succeeding and growing. Another consideration for the potential of many of these business models is that the different toilet designs may require changes in behaviour around usage such as the use of urine diversion in households, the addition of compostable waste.

2.5.1.3 Collection Businesses

Transport is often a huge constraint to providing urban sanitation with dense areas that are often inaccessible to vacuum trucks or sewers often desired by municipalities. Through the interviews a series of different services and approaches to transport were discussed.

An interesting model arose in Ethekwini, Durban where the model approach decided to provide a service of manual emptying that was sub-contracted by the municipality. Instead of looking at new technology they decided that a uniform service could be provided by giving manual emtpiers the proper safety equipment and then not going as deep in pits (Eales, 2005). This was mainly chosen out of pragmatism recognising that a lot of the urban areas were difficult to access due to the urban layout. This was an interesting model as the lower depth provides a view to another model suggested in the interview where latrines are emptied to a shallower depth but more regularly. Often studies find that the main concern is odour so perhaps when looking at serving communities emptying a smaller volume may be acceptable whilst providing more regular demand. There would be a question of how to sell this model to people and change so that they are happy with a reduced emptying volume.

Another model discussed with an NGO supporting enterprises was similar in the aim to change the management model rather than introduce new technology. Here a transport business which is leased out to entrepreneurs to use a truck for emptying latrines is suggested. The challenge in this model is having a person or institution with the initial capital to fund a business based on leasing out vehicles, which if successful would reduce the constraint of access to finance for sanitation enterprises. When looking at such a transport business the key function for

profitability is to be able to carry as much sludge as possible in a day to cover the leasing fee. A hopeful option for increasing the efficiency of this model is to model the truck as a mobile transfer station rather than an emptying and collection service. Currently a lot of time for trucks is spent waiting while a pit is emptied whereas a different model would use trucks for collection of drums that have already been filled.

2.5.1.4 Treatment Businesses

A couple of informal discussions were conducted with people based in sanitation businesses that either operated in treatment with resource recovery as a standalone business or as part of a full collection chain. The financial viability of resource recovery had mixed opinions from interviewees whether it was actually viable to change the sanitation situation. An interviewee from Water and Sanitation for the Urban Poor (WSUP) involved in implementing resource recovery revenues from resource recovery are fairly minimal and would not fund whole sanitation chain, instead only having a small impact. Another working in sanitation markets with Waste Enterprisers said that there'd been anecdotal evidence it could sell but the real challenge in these models is the social challenges in uptake particularly when the resources can be related to providing food, such as plants being grown with fertiliser or directly growing fish. Resource recovery as an indigenous business that could be grown this was less often done, with an interviewee from water for people saying that they were often heavily supported by NGOs. The only evidence of an indigenous business in this area was anecdotal about a businessman who would pay for people's sludge if it was thick and would have qualities as a fertiliser.

A larger business attempting to treat faecal sludge or sewage and harvest profits yielded some interesting information about the challenges. Initially a potential option was to use WSPs for growing fish that could be sold as food. Quite a lot of technical challenges were encountered attempting to do this and for success it was suggested that it would need extra finance to get an experienced aquaculture expert to make it work as they informally agreed that they had debunked the idea of a low-tech business model of aquaculture. There was also a need to get a better technical understanding of the supplementary feed required, aeration technology and market supply options. The other fundamental part of this model was to work with existing WSPs because the sanitation infrastructure is prohibitively expensive to build for private sector companies. Larger cities can have a larger infrastructure existing for a

model like this but the plants are already operational, so it would not serve a business model providing improved sanitation unless used to subsidise collection in low income areas. One question that had not really been answered about aquaculture was the social challenges in getting it to market and whether people would actually purchase the fish.

2.5.1.5 Financial and Business Development Services

There are a series of businesses looking to aid sanitation improvements through the provision of finance, either to households or to businesses. A lot of these businesses also look to provide training to sanitation entrepreneurs, enabling them to improve their services. This area of sanitation businesses was available in the IRC business catalogue with the majority of the organisations being based in Asia, with Captiva Africa, FMSEDA and TEEC's based in Africa.

The model of these businesses is commonly based around providing flexible financing for customers to invest in household sanitation technology such as toilets or latrines, and then to provide training to the entrepreneurs who sell these products. These businesses provide an important role in improving sanitation as a common finding of different research is that entrepreneurs can be lacking in the skills to scale up operations and provide services to a large urban population (Trémolet, 2012; Gero, et al., 2013; Sy, et al., 2014). Looking at the implementation of Ecosan toilets as a business in Kenya, Ethiopia, Uganda and Tanzania the need for access to finance was cited by Van der Wel et al (2010). This is part of a report on a project looking at resource recovery and had a group of pit emptiers and stakeholders such as local banks to discuss the issues in sanitation. The research is an interesting viewpoint into informal entrepreneurs and their environment and circumstances, though says less about what may be the challenges in larger sanitation businesses that may exist in African cities. Lack of finance at the level of medium and large businesses is also cited as a key constraint to both setting up and expanding sanitation businesses (Chowdhry & Kone, 2012). Finance is also a key element in enabling customers who may be unable to save up money to pay for services flexibly (Ayele Shewa, et al., 2010; Davies & Tinsley, 2013). Davies and Tinsley (2013) present findings from the WaterCredit initiative which aims to provide loans for household water and sanitation in India and Kenya, from the uptake in loans by over 500,000 people the paper clearly identifies that finance can assist household access to finance even at interest rates of 15-20% per year. Whilst it is presented by

people from the project it still highlights the issues around microfinance partners and operation and monitoring suggesting that it is a reliable source. Its findings more imply that the difficulties go beyond simply providing enough money to access finance and move into issues of who provides the loans, how they are monitored and how to make sure there is still access to sanitation for those too poor even for loan-based payments. The availability of businesses providing finance and training such as this could be very influential in the success of sanitation entrepreneurs in West Africa so research may look to investigate beyond entrepreneurs providing direct services and products and to the available support systems, which includes micro finance providers.

2.5.2 Economics of Sanitation Providers

Looking at collection businesses across Asia and Africa, the potential for profit in collection and transport of faecal sludge exists and is likely to be more successful if the businesses can scale up (Chowdhry & Kone, 2012; Kome, 2011). A few other businesses seemed to only profit through unregulated activities such as illegal dumping (Anh & Sam, 2013; Tyler, et al., 2013). Assessing the sanitation markets, there was very small profit margins found for SSIPs once the costs of dumping, renting equipment and getting permits was accounted for (Trémolet, 2012). Costs of renting equipment show the benefits of scale where someone would be able to own equipment increasing their earnings long term. This section will look at other findings of the main sources of costs and revenues of sanitation as a business with resource recovery.

2.5.2.1 Profit of Resource Recovery Business

2.5.2.1.1 Vietnamese Faecal Sludge Management Businesses

There have been few rigorous studies looking at the financial potential of a resource recovery business in sanitation. The largest scale of analysis is in an analysis of Vietnamese FSM businesses, where the treatment plants use a form of resource recovery in each city studied, and different management options to increase treatment are analysed (Anh, et al., 2011). In the current form the businesses often save on transport costs by avoiding use of the safe disposal points which enables the businesses to make modest profits.

In Hanoi as shown in Figure 2-4, the cost recovery from composting does not seem to cover the additional costs for bringing sludge to treatment points and instead the options suggested are to either subsidise safe emptying from the city budget, which

would still find many businesses modelled failing to profit, or enforce better practice through regulation, marketing and scheduling to force efficiencies in the business. Looking at the large Hanoi utility it is possible to see the impact of compost cost recovery, with an annual revenue of USD21,845, which is similar to tariffs for emptying government building but not enough to subsidise the full operation of the business. The treatment plant is actually underused in Hanoi in terms of compost production and suffers with poor sales due to an uncompetitive price, limited marketing and low product quality. The loss in this treatment is subsidised by the revenue of URENCO. One of the key problems found in the analysis is that more plants could help to support the FSM chain businesses in bringing waste to safe stations, which combined with effective marketing could increase the economic benefits of treatment.

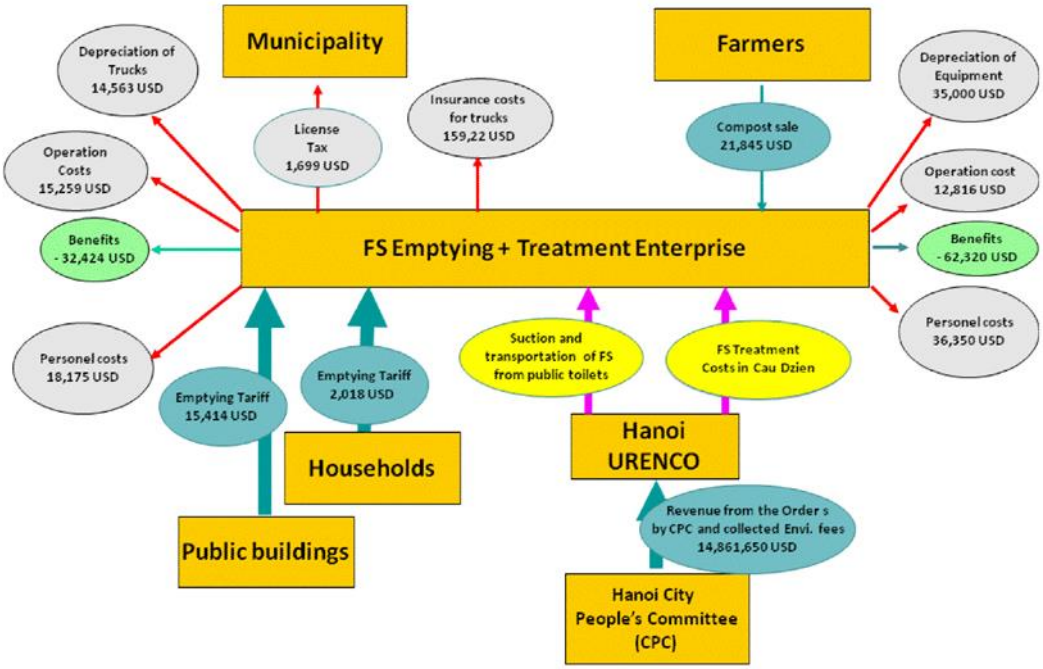

Figure 2-4: Faecal Sludge business models of Hanoi (Anh, et al., 2011)

In Hai Phong, as shown in Figure 2-5, the large utility responsible for treatment is again cross-subsidised by other activities within the company. There is a problem with not enough businesses bringing waste to the treatment point operated, and then the compost produced is of such a poor quality that it cannot really be used to profit in the open market, with the first sale only generating USD728 which is insignificant in the scale of the operating costs of treatment. The emptying businesses are more profitable in Hai Phong, and would achieve capital recovery within 5 years in the modelled option of bringing all waste to the treatment plant for

an additional charge of up to USD1.94 per m^3. The importance of transport costs can be seen in the additional profit in medium enterprises in Hai Phong that spend very little on transport as they do not empty at treatment plants resulting in a fuel cost of USD702 per truck per year as opposed to USD3835 in Hanoi. The emptiers are more profitable when modelled as taking all sludge to a treatment point than in Hanoi partly because of a reduced transport cost with a round trip of 15km instead of 26km.

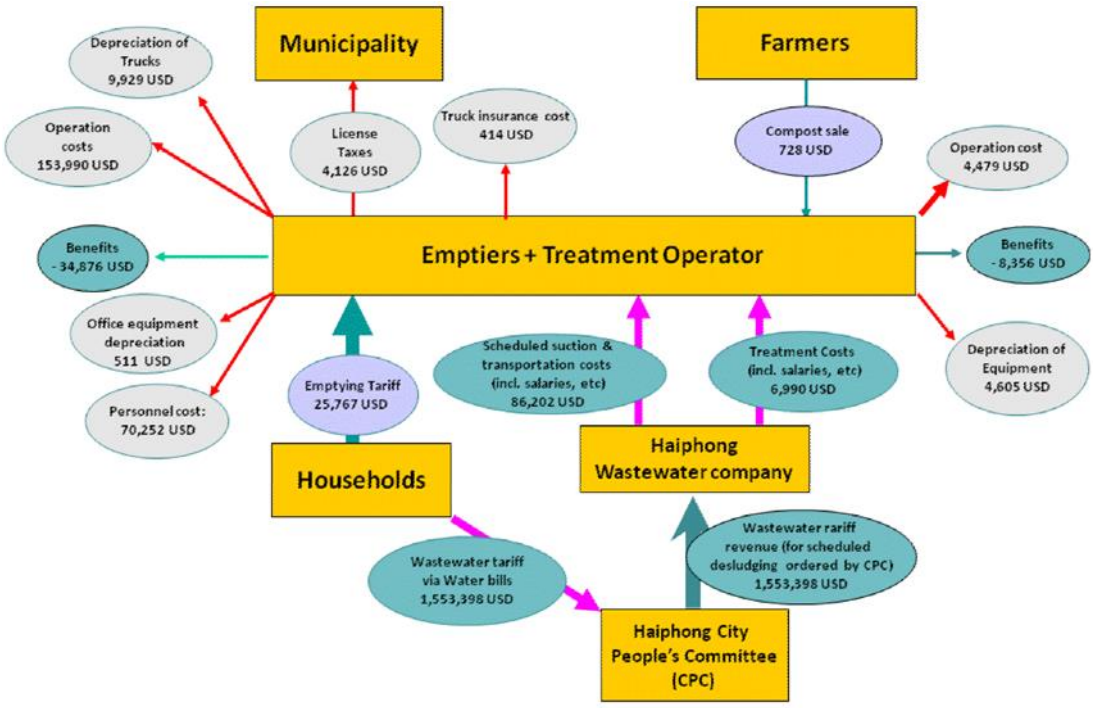

Figure 2-5: Faecal Sludge Business in Haiphong (Anh, et al., 2011)

Ho Chi Minh is the only city where the large utility is profiting without cross-subsidy, however the majority of the revenue for this is from leasing public toilet cabins rather than treatment operation. There is a large difference in revenue with private emptiers in Hai Phong making USD11303 revenue per truck, Hanoi USD23041 and Ho Chi Minh USD31607. Ho Chi Minh enterprises are mostly able to profit without extra charges for safe disposal, except for one enterprise that would profit at a charge of USD8.50 per m^3. There is compost generated from treatment plants which is sold in the markets where there is a large demand for fertiliser. The financial data for the treatment business in Ho Chi Minh was not available however it is known to charge USD1.46 per truck for dumping as well as revenue from composting showing that revenue is needed from more than just the resource.

The different results from Hanoi show the potential for composting to be practiced at city scale and provide an extra source of revenue to businesses or utilities operating treatment making it more sustainable, though they do not show the potential for resource recovery to be a standalone business model. There is a need for good quality management and marketing to enhance the revenue generation from treatment. The treatment businesses in Hanoi and Hai Phong cannot survive alone on the revenue from resource recovery and either use dumping charges or cross-subsidy from other activities to remain financially sustainable. From the emptiers perspective, the research provides interesting data as to whether treatment with resource recovery can provide a business model where it is more profitable to dispose waste safely than to dump and cause environmental damage. In this context the large transport distances meant it was not profitable for businesses to bring waste to the dumping stations instead of dumping locally. Instead systems of either better regulation or financial incentives are suggested. The payments to emptiers and operating costs could not be supported alone by the resource recovery showing that the treatment-based compost is insufficient to create a business model that is only profitable with good practice along the FSM chain. What is clear looking at FSM is the impact that transport networks have on the profitability of emptying businesses if disposing at a treatment point, with businesses in Hai Phong modelled to be more successful if safely disposing all waste due to the reduced transport distance compared to Ho Chi Minh and Hanoi. If there is to be sufficient incentives for safe disposal of waste there must either be financial incentives to cover the cost of transport or reduced transport distances.

2.5.2.1.2 Waste Enterprisers Kumasi/Pivot Kigali

Waste Enterprisers is a business that entered the Faecal Sludge market in Kumasi, Ghana to look at resource recovery as a source of profit. They attempted two different models of a business to attempt to finance the sanitation chain. Firstly they used WSPs in small communities to raise fish as a source of profit. This mainly stayed in the research stage due to many different challenges that included (Waste Enterprisers, 2012):

- Cannibalism amongst fingerlings in growth pond losing product due to use of catfish (recommend trying Tilapia instead)
- Balance of using supplementary feed and downstream pollution as a result
- Bottom dwelling nature of fish leading to health and safety risks

- Low oxygen in maturation ponds with overnight levels less than 1mg/l
- Ponds never perfoming as designed due to vegetation, poor design and lack of O+M
- Lack of expertise about commercial fish farming

A lot of these problems had solutions suggested such as supplementary feed, aeration, using different fish but they have cost implications which may affect the margins. The costs of hiring commercial fish farmers particularly was listed as an impediment to future profitability. The venture of fish farming was eventually left due to doubts about the profitability of the function in Kumasi however interviews with a member of the force suggested it could still have potential at large sites such as Nairobi treatment plant, but that would not bring any sanitation effects so was not pursued. A further research option investigated was the potential of producing biodiesel from faecal sludge but the yields were discovered to be incredibly low so were not considered a commercially viable business model.

Moving on from this they rebranded and became a business looking at producing biofuel for heat in industry, finding that with a drying plant they could get a solid fuel depending on the quality of the pit. This fuel has a yield of a grade C coal of calorific value 17MJ/kg making it suitable for industry in cities where there is sufficient requirements (Murray Muspratt, et al., 2014). One of the questions for the model is how centralised it is for transport methods, which is vital as shown in the Vietnam study. There is a potential for drying at more localised points and then centralised final treatment which yields economies of scales. The Pivot model is still at pilot scale so has not been realised yet but the researcher hopes to maintain contact as it progresses.

2.5.2.1.3 Sludge Reuse Value Analysis

Another academic project analysing economics of resource recovery is by Eawag looking at the potential value of different resources in different cities. The four different product markets investigated were combustion fuel, insect larvae, biogas and soil-conditioner. Soil conditioner was found to be the least economically valuable resource, but the most practiced currently (Diener, et al., 2014). The value in Dakar of faecal sludge for this purpose was half of that of animal manure due to acceptance issues. Figure 2-6 shows the market value of different products in different cities from research.

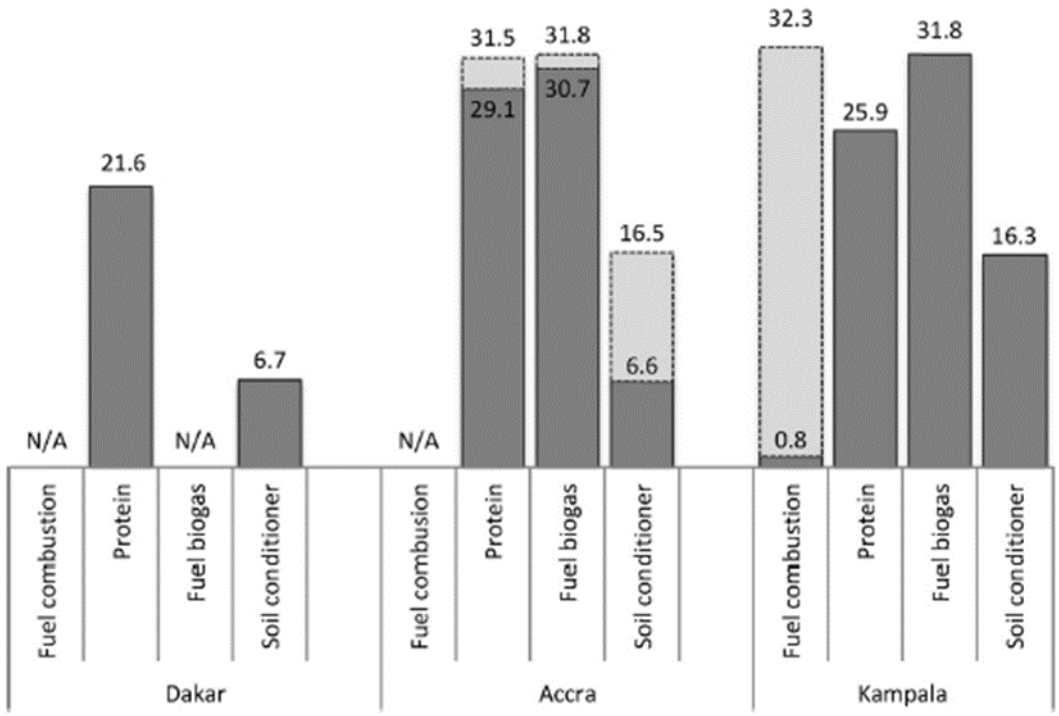

Figure 2-6: Potential Market Value (USD) of Different Products Derived from Faecal Sludge per tonne dry weight (Diener, et al., 2014)

2.5.2.1.4 Comparative analysis of different approaches

Murray, Cofie and Drechsel (2011) investigated the economic potential of a range of waste treatment options based on a population of 100,000 people, with the different economic data shown in Figure 2-7. The data for the paper comes from a range of different contexts making a comparison of different options inappropriate; for example the household biogas data is based upon Nepal whereas centralised is based in Ghana so the two cannot realistically be compared. The information for centralised biogas and agricultural models are mostly based in Ghana though which provides a useful guide as to the potential of these approaches. Centralised biogas production would seem to be a potentially profitable system in Ghana from the paper but requires a large capital investment of around USD1 million for a system serving 100,000 people. Despite its grounding in Ghana, with it being second hand data it is hard to know the methods that were used to get these economic costings and from whom they came. The biogas economics in Figure 2-7 do not include the capital cost of equipment related with compression and distribution of biogas. This can be a large challenge to redistributing biogas to use for fuel (Kapdi, et al., 2005).

The use of co-composted faecal sludge or raw faecal sludge in agriculture would also appear to be potentially profitable approaches to waste management for a

population of 100,000 people from Figure 2-7. This is less clear in practice however where a research project in Ghana found a low willingness to pay for co-composted faecal sludge in Kumasi to the point that sales would not be able to cover production costs (Cofie & Kone, 2009). This shows the discrepancy between theoretical market value of products and the actual value that can be realised in specific social contexts.

Reuse Option	Capital costs linked to reuse ($)	Operating and Maintenance Costs ($)	Hypothetical market value of input ($)	Incremental benefit ($)
Direct (untreated) use				
Urine	3,750,000 ($150/household for UDDT) + 6000 (urine storage)	660,000	240,000	600,000
Raw faecal sludge	0	0	326,000	458,000
On-farm treated wastewater	75,000	110,000	NA	559,000
In-situ use				
Household biogas recovery	8,750,000 ($350/household)	0	4,811,000 ($200/household.year)	NA
Centralised biogas recovery (Gas and Electricity Respectively)	983000 1,045,000	43,000 47,000	193,000 76,000	 NA
Aquaculture	14,000,000 (WSP) + 1000 (aquaculture)	150,000 (WSP) + 54,000 (aquaculture)	NA	220,000
Post-treament use				
Dewatered faecal sludge (fuel)	65,000	12,000	335,000	NA
Dewatered faecal sludge (soil conditioner)	65,000	11,000	73,000	472,000
Co-composted faecal sludge	93,000	168,000	518,000	880,000
Treated wastewater	14,000,000 (WSP) + conveyance costs	150,000	52,000	559,000

Figure 2-7: Economic Analysis of Different Approaches to Wastewater or Faecal Sludge Treatment (Murray, et al., 2011)

2.5.3 Constraints to Sanitation Providers

2.5.3.1 Public Monopoly to Private Monopoly

A large driver for the involvement of private sector in services in Sub-Saharan Africa was the weakness and inefficiency of the state (Bayliss, 2003; Budds & McGranahan, 2003). The introduction of the private sector into services was expected to drive cost efficiencies and improved services in water, sanitation and other industries. One of the key drivers for private sector innovation is competition, which is difficult to achieve with water and sanitation services that are often natural monopolies (Kirkpatrick, et al., 2006; Yeboah-Assiamah, 2015).

Services are often unbundled to attempt to introduce more competition where monopolies have existed (Budds & McGranahan, 2003; Bayliss, 2003). The two sections of FSM in Ghana that have been unbundled and had private sector involvement are public toilets and sludge collection and transport. Public toilets could be argued to constitute a 'geographical monopoly' when they are sparsely spread throughout areas meaning someone can rarely choose between a number of options. The competition is instead in the leasing process, though this process has often been a source of the politics of patronage in Ghana (Caplan, 2010; Ayee & Crook, 2003).

2.5.3.2 Regulation

In a monopoly market system the presence of strong regulation is vital. Unfortunately in developing countries the capacity to enforce regulations can be very weak (Yeboah-Assiamah, 2015; Laffont, 2005; Lee & Floris, 2003; Kirkpatrick, et al., 2006). The varying presence of regulatory structure in Argentina and Chile was cited as one of the key reasons for the varying results of water privatisation (Lee & Floris, 2003). Regulation is also key in the process of contracting out services to the private sector to ensure that the best option can be achieved, but many different studies have found evidence of governments failing to do so in Sub-Saharan Africa. Common issues include the awarding of contracts without an open process (Nyarko, et al., 2011; Kayaga, 2008; Ayee & Crook, 2003) or 'dive bidding' where companies make unrealistic bids for contracts only to renegotiate terms once the competition has been removed (Budds & McGranahan, 2003). Issues often arise when there is an unclear delineation of responsibilities as to what tasks are the responsibility of the private and public sector (Nyarko, et al., 2011; Kayaga, 2008). It is important in this case to have regulatory capacity in place before privatisation to

ensure that contracts can be satisfactorily made with clear conditions (Bayliss & Fine, 2008). Alternatively, when looking at models with resource recovery the aim is to look at models that can in effect be 'self-regulating' due to the profit incentive of producing biogas, compost or aquaculture products.

2.5.3.3 Recognition/formalisation

Recognition and formalisation of slum dwellers and informal businesses has been often cited as a huge potential for increasing economic productivity in Sub-Saharan Africa (Moyo, 2011; De Soto, 2001). With an industry like sanitation the informality and invisibility of service providers is even more of a risk due to the public health aspects of sanitation services.

The problems of individual entrepreneurs lacking recognition exist in sanitation and were found across Ethiopia, Uganda, Kenya and Tanzania (Van der Wel, et al., 2010). Here individual entrepreneurs working in sanitation were unregistered and completely unrecognised by municipalities, and risk being chased away more than other sectors as people can look negatively upon sanitation and they could be considered to be making city less hygienic (Van der Wel, et al., 2010). The approach taken in this project looked to set up a workshop for policymakers and other stakeholders about the role and work of informal entrepreneurs, with meetings set up to introduce them to the 'invisible entrepreneur' (Van der Wel, et al., 2010). It has been further suggested in the market analysis of urban sanitation that more support is needed for informal providers to get them established and provide them with skills and access to credit (Trémolet, 2012).

The issues with a lack of formal recognition for the informal providers of services can be seen not only in sanitation in Sub-Saharan Africa but also in water and solid waste management. A large project was conducted by Water, Engineering and Development Centre (WEDC) at Loughborough University into small water enterprises (SWEs) across four countries: Tanzania, Kenya, Sudan and Ghana. Sarpong and Abrampah (2006) looked at the environment for small water enterprises in Accra, Ghana, using a desk study on Ghana, interviews with key informants across the government and surveys with businesses in the area. This study provides a good insight into the relationships and challenges that define water supply in a large city in Ghana, and may have implications for sanitation also. A major category of SWE found were water tanker operators (Sarpong & Abrampah, 2006), who transport water in bulk. This water is then distributed by vendors to

people who do not have access to a direct water supply. The management model used is of interest, as while each tanker is owned by an individual, they are formed into associations which have a formal relationship with Ghana Water Company (GWC), the utility responsible for drinking water provision (Sarpong & Abrampah, 2006). According to Sarpong and Abrampah (2006) this relationship allows them to negotiate provision of hydrant points and set prices, however there is still limited relationship and it could be improved if SWEs and tankers were integrated into strategic planning to serve customers. GWC has a perception that the association is exploiting a gap in the supply for profit, but would improve its supply if it recognised the role provided by SWEs (Sarpong & Abrampah, 2006). The project found similar issues with SWEs requiring recognition in Kenya (Oenga & Kuria, 2006).

Oteng Ababio et al (2013) looked at the provision of solid waste management in Accra, a similar business in terms of emptying and disposal. The research is grounded in long term fieldwork with in-depth interviews with key stakeholders in waste so is a good insight into the issues of solid waste management in Accra. Recognition of small scale entrepreneurs was found to also be an issue in the solid waste management industry in Accra, Ghana despite informal practice being discouraged by city authorities (Oteng-Ababio, et al., 2013), showing a common theme of the service provided by small scale entrepreneurs being not appreciated or even discouraged across different areas of service provision despite often being the only option. An example of a more favourable approach taken to formalising these entrepreneurs is in Belo Horizonte, where in 1990 they formed a waste pickers association which was integrated into the Municipal management framework in 1993 and established a recycling plant for plastic in 2005 (Oteng-Ababio, et al., 2013). This recognition and integration not only helped the municipality to provide an essential service, it provided extra jobs and better conditions as the association grew from 31 to 380 members from its formation (Oteng-Ababio, et al., 2013). A similar example of integration and recognition of informal entrepreneurs was shown in Maputo, Mozambique. Here, there was no collection service in many areas and informal entrepreneurs worked to separate waste at a municipal landfill in bad conditions (Oteng-Ababio, et al., 2013). The workers were registered as cooperatives in order to work as a group and were integrated into the formal management framework for solid waste. The small enterprises now cover 45% off the poor areas of the city giving waste collection to nearly half a million citizens (Oteng-Ababio, et al., 2013). The other outcomes have been a local recycling plant

that operates without external finance, 250 jobs provided by enterprises and better wages and conditions for the workers (Oteng-Ababio, et al., 2013). These experiences in the Solid Waste Management sector show the potential for provision of services from existing entrepreneurs through better integration into city planning and formal recognition as opposed to discouraging and ignoring the work and services provided.

2.5.3.4 Scale of Operation

A challenge with urban sanitation entrepreneurs providing services is the ability to scale up services to a level that can provide impact in a city. An analysis of sanitation markets found that the proliferation of SSIPs without support was likely to inhibit their ability to scale up and benefit from economies of scale (Trémolet, 2012). The main issue cited with being able to scale up sanitation providers is financial. From conversations with different NGOs supporting sanitation providers, the issue of funding and financing expansion of SSIPs was tied in with the issue of formality and recognition by governments as many entrepreneurs would lack a birth certificate or social security number so are unable to get funding to expand their services. This leaves a fragmented market of small providers. The issue of scale of businesses was also cited as a factor in sustainability and success of business in a report looking at sanitation transport providers (Chowdhry & Kone, 2012) where trucking businesses with a single truck were unstable and earned a lot less per truck than larger businesses. This was found to be linked to finance issues as most single truck businesses had usually started with personal savings or loans from family or friends but were unable to access finance due to lack of collateral and high interest rates leading to a proliferation of unstable single truck businesses.

There are also technical constraints to sanitation providers scaling up their services in dense urban areas where they are likely to be manual emptiers, which need a transition from small transport to big transport such as trucks to take the waste to centralised treatment plants. This was cited in conversations with an engineer working in Ghana as a major challenge to the business scaling up. As discussed in the technical section the solution could involve waste transfer stations or decentralised treatment plants which would both require technical expertise in design and have land requirements (Tilley, et al., 2014) in areas where it may not be clear who the owner of the land is and how to contractually buy it.

2.5.3.5 NGO Culture

An aspect of supporting entrepreneurs in providing sanitation in low income urban areas with assistance from NGOs is how the culture and aims of the NGO and donor can interfere with the process of building a sustainable sanitation business that can generate income. This aspect of the approach that NGOs take to supporting entrepreneurs was found both in literature and in conversations with NGO workers. In the systematic review of sanitation enterprises there were different papers cited stating that enterprises needed to take on more of the risk as part of the business model to create ownership of the operations and business (Gero, et al., 2013).

Another element of where NGOs can interfere with the sustainability of sanitation is the provision of subsidised, or free, infrastructure (Schaub-Jones, 2010). This can have two effects that harm people providing sanitation for income in that the cheaper products and service can undermine the local businesses operating, but it can also reduce demand with an expectation of free or subsidised products as seen with entrepreneurs in rural Malawi providing latrines (Holm, et al., 2014). This lack of demand may be a crucial barrier to someone being able to provide services as a business. This experience of people expecting things for free was often cited in conversations with different NGO employees working in the area of supporting sanitation businesses.

2.5.3.6 Access to Finance

One of the major motivations cited for private sector involvement in services is their ability to finance developments where governments cannot (Yeboah-Assiamah, 2015; Sohail & Cavill, 2009). The importance of being able to access finance to enter the sanitation market can be seen across various sources of literature (Gero, et al., 2013; Chowdhry & Kone, 2012; Sugden, 2013a; Holm, et al., 2014). At the larger scale end of the business Chowdhry and Kone (2012) demonstrated the fact that the profitability of businesses was only sustainable once businesses moved beyond single truck operations, which were usually sourced on private finance from families or friends. Looking at informal and small scale providers there was a barrier to sanitation as a business for entrepreneurs in rural Malawi as there was limited financing options to enter the market (Holm, et al., 2014). This was also cited by Sugden (2013a) as a challenge to enabling small scale entrepreneurs to enter the sanitaiton market as to get a loan they needed such large collateral that it negated

the benefit of start-up finance. This is often due to the reluctance of financing institutions to fund risky or new sanitation businesses (Van der Wel, et al., 2010; Chowdhry & Kone, 2012; Trémolet, 2012).

2.5.3.7 Business and Marketing Skills

One of the largest challenges to sanitation providers operating in urban slums and providing impact is the technical expertise and business skills of SSIPs (Sy, et al., 2014). The report looking at sanitation markets targeting the poor found that providers were lacking experience in marketing their skills and creating value (Sy, et al., 2014). Water for People had a similar experience attempting to support masons as providers who were not open to improving their business skills (Sugden, 2013b). It was the belief of Sugden (2013b) that training a business person in sanitation was more effective than trying to train a sanitation provider in business, so the approach taken was to work with Business Development Services (BDS) that could find entrepreneurs who could enter market successfully.

2.5.3.8 Demand

A key bottleneck for developing sanitation has been identified as the irregular, or lack of demand for products and services in sanitation (Sy, et al., 2014). One element of failing demand in sanitation provision is emptying and transport, where the demand can be seasonal depending on whether season is wet or dry, inhibiting the ability of latrine emptying to provide a steady reliable income (Gero, et al., 2013). Another challenge found is the general lack of demand and unwillingness to pay for sanitation products (Sy, et al., 2014), with suggested solutions including increasing demand through education and encouraging larger businesses in to the on-site sanitation sector. Another method which has had success in promoting demand has been the Community Led Total Sanitation (CLTS) movement (Trémolet, 2012). This method uses community level triggering of demand to force behaviour change, particularly in rural areas.

A key understanding to enabling a sanitation business to succeed would be to look at the elements of sanitation that are most important to local people and therefore what are the most important aspects of the business.

2.5.3.9 Motivation of Entrepreneur

Prahalad introduced the theory of bottom of pyramid (BOP) development in 1999 (Prahalad & Hart, 1999) with the belief that private enterprise and profits can relieve

poverty on a large scale. One of the challenges in entrepreneurs and businesses providing services at the BOP lies in the willingness to provide services at the BOP. The potential for running sanitation businesses has been held back by beliefs about viability in the poor areas and a case that it may be immoral to profit from providing basic services to the poorest people (Mulumba, et al., 2014). In a world bank project investigating the market for providing sanitation 63% of businesses in Tanzania indicated that poor customers do not pay in a timely way, and more than 75% say they are hard to service and access (Sy, et al., 2014). Work from Building Partnerships for Development (BPD) also found that as entrepreneurs became more formal they looked to gravitate towards institutional contracts with regular payment and away from household services (Bereziat, 2009). A similar challenge was found with emptying businesses in Malaysia being unlikely to accept customers that are either remote or difficult to access (Kome, 2011). The dense urban areas of interest in this research are unlikely to be easily access by existing methods such as vacuum trucks or sewers but more manual methods with a method of transfer or a localised treatment centre could work. This is an issue tackled by Prahalad who hoped to encourage large multinational corporations to enter the BOP market, whereas the hope here would be to ensure that expanding SSIPs do not deviate away from serving poor people. The case for serving poor people is viewed as a case of the scale of the market, with such a huge urban population without access to sanitation a good business model has the potential to expand massively even if the margins are small.

2.6 Gaps in Literature

From the review of academic literature, grey literature, and informal conversations with different workers in the sanitation industry, a series of gaps in knowledge have been identified for looking at wastewater or faecal sludge treatment with resource recovery.

2.6.1 Gaps between Grey Literature and Experience

Often NGO publications and presentations are written with the purpose of publicising activities or accessing funding, in this sort of literature there can often be a gap between what is written and experiences of workers on the project. This can be true of business initiatives or new projects working on development where the actual information that is not published can be valuable in terms of understanding the political, technical or social challenges with different approaches to sanitation.

This suggests there is a large gap of knowledge dissemination between what is published by NGOs and in academic literature and knowledge that exists with experts and people who work in the sanitation industry.

2.6.2 Smaller City Context

Often the literature found from both academia and NGO sources was focused on the larger cities within developing countries. Often this would be focused on either the capital city of a country or a second economic city within the country, with most research in Ghana looking at Accra or Kumasi whilst research in Malawi seems to be based around Mzuzu or Blantyre. Reasons for this trend includes the presence of more universities that can conduct local research, more NGOs and government institutions to with which to work and larger populations. Today, over half of Africa's urban population still lives in urban areas smaller than 500,000 population, and the fastest growing urban areas are medium-sized cities and cities with less than 1 million population in Asia and Africa (UN, 2014). This growing trend of urbanisation indicates a need to focus research on the context of smaller, growing cities. For example, smaller cities may have fewer issues with large transport distances and densely packed urban areas than are noted in the literature about larger cities. This is illustrated in the financial modelling of Hai Phong where the market for emptiers is efficient enough that profits can be maintained with safe disposal due to low fuel and transport costs compared with larger cities like Hanoi and Ho Chi Minh, but the risks are also illustrated in that it has to compete with a model of illegal dumping that has proven to be very profitable. There may also be fewer industrial functions with a demand for combustion fuel which was seen as profitable in the Fame project. The increasing proportion of agricultural activity may make larvae for animal protein such as black soldier fly or co-composting a more suitable resource option. It is considered of interest to look at potential markets in smaller cities instead of capitals and major economic hubs, partly because of the increased potential for profit margins of emptiers due to reduced transport but also because of the limited research looking at markets in these sorts of cities and the different dynamics that may exist. The size of the city may also offer the opportunity to integrate sustainable systems into the urban planning dynamic before they grow into larger populations for whom it is more difficult to retroactively plan urban infrastructure.

2.6.3 Economics of Resource Recovery

The literature about resource recovery models is quite limited, and the wildly varying geographies and contexts in which the economic analyses were conducted in makes comparing different models very difficult. For example, labour and fuel costs of operating the ladepa treatment model will be largely different from the labour costs that would exist in Malawi or Ghana. Therefore, for the potential of resource recovery treatment systems to be assessed there needs to be an economic analysis of different potential technically feasible models in the same context to compare directly. Only then can the question of whether self-regulating faecal sludge treatment models can operate in African cities be answered.

2.6.4 Social Acceptability of Different Resources

Much like the case of economic analyses of resource recovery, the assessment of social acceptability of different resource is very geographically spread and rarely carried out in a comparative method. Instead, research is often based on seeing whether a pre-selected resource would be acceptable, whilst ignoring other suitable systems that could be implemented. It is therefore impossible to compare separate papers in different areas looking at the potential for aquaculture or agriculture projects. To assess the potential for faecal sludge treatment with resource recovery to operate as a self-regulating business model the acceptability and feasibility of different resources needs to be compared in the same local context as well as the technical and economic feasibility.

2.6.5 Effect of Treatment Initiatives on Upstream Faecal Sludge Management Chain

The conclusion of the Fame report states that resource recovery '*could'* provide an economic incentive to encourage proper functioning of the sanitation chain but it does not provide the other side of the economic analysis to see what level of incentive would be needed to encourage emptiers and transporters to bring waste to a treatment and re-use point. This would be dependent on transport distances, methods, treatment costs, equipment costs and the strength of regulation and enforcement as well as the revenue generated from resource recovery. There is no conclusive evidence of a business model that achieves all these aims currently, but the research from different papers does imply it may be possible. Any potential system requires a balance of products suitable for local markets and cheap operation of technology, together with an environment where customers are not incentivised to dump waste illegally instead of safely disposing.

2.6.6 Capacity of Informal Providers and Private Sector to Provide Treatment Services

There has been limited involvement in wastewater treatment from the private sector across sub-Saharan Africa, and little to no involvement from SSIPs. To understand the possibility for treatment to be operated with resource recovery so that the profit from resource recovery enforces proper operation, the capacity of different institutional arrangements to properly operate systems of varying level of complexity needs to be understood. For example, operating aquaculture systems has been shown to be fairly low in maintenance and operational issues whilst biogas systems require substantial technical expertise so the capacity of local institutions in the research context needs to be assessed for each system.

2.6.7 Understanding of Interaction Between Technical and Social Factors

Looking at the social reasons for failure in potential systems is often studied in isolation from technical studies of potential systems, ignoring the interdependency of both aspects of socio-technical systems. The cross-relationship between these factors and technical systems need to be understood in order to fully assess the potential of resource recovery as a safe treatment system for cities in Sub-Saharan Africa. The potential for engineering approaches that could combine more comprehensively interlinking factors of technology operation could help to fill this gap.

2.7 Considerations for Research based on Literature Gaps

Based on the literature gaps identified in section 2.6, a series of considerations and targets were made for the research to ensure it was able to fill as many gaps in the literature as possible. These are listed below:

1. Conduct informal interviews and conversations with NGOs and researchers associated with grey literature in projects related to resource recovery in SSA to learn more about actual experience: **2.6.1**
2. Target the research in smaller cities to allow the research to provide greater detail about sanitation systems and treatment dynamics in smaller cities in SSA with reduced transport distances and populations to serve: **2.6.2**
3. Incorporate economic assessment into assessment of any designed system of resource recovery for smaller cities: **2.6.3**
4. Ensure that any resource recovery models also have a social acceptability as well as a theoretical economic potential to ensure they are actually profitable in practice: **2.6.4**
5. Consider economics and interconnectivity of all stages of sanitation chain when assessing treatment options: **2.6.5**
6. Assess market environment and private actors in research areas to consider technical and financial capacity for private sector to provide faecal sludge treatment: **2.6.6**
7. Identify modelling approaches and systems that can explore interactions of socio-technical systems: **2.6.7**

3 Methodology

3.1 Section Structure

Based upon the need to investigate social, political and market-based issues of sanitation in small Sub-Saharan African cities a framework of questions for identifying potential re-use systems is identified in Figure 3-1.

This section builds upon the gaps identified in the literature review then looks at literature about research methods to identify a research approach to answer the questions identified in Figure 3-1. Section 3.2 reviews the literature around practical issues conducting social research particularly in developing countries and in different cultures. Section 3.3 looks at the different approaches and methods that can be applied when answering social research questions,

and presents the research approach of case studies for the thesis with different methods pragmatically applied for different sub-questions. Having defined the approach for data collection relating to answering the main research questions, section 3.4 explores the potential methods of assessing designs for future viability with an emphasis on ABM due to the socio-technical nature of the systems being studied.

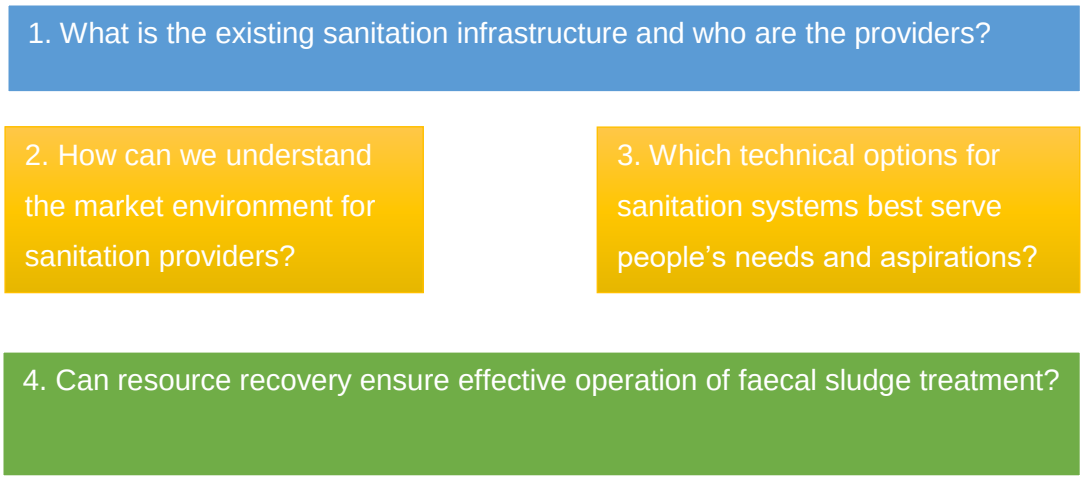

Figure 3-1: Framework for identifying suitable sanitation systems with re-use

3.2 Conducting Social Research

3.2.1 Researching in a Different Culture

3.2.1.1 Language Considerations

A large challenge in understanding the social barriers to implementing sanitation technologies in urban communities is ensuring the reliability and accuracy of information obtained from social research. One of the considerations of this is the difficulty of conducting research across language barriers. In the field of development work Scheyvens (2014) argues that without a good grasp of the local language the product of the research will likely be a poor interpretation of the reality.

The first consideration of language challenges in research is at the literature review stage, where a potential problem cited in development work is that there may be literature that is inaccessible to the researcher due to language barriers (Scheyvens, 2014). This has already been experienced in certain areas by the author as there are certain NGOs with French publications, such as Hydroconseil, and government reports have been used to assess sanitation provision in different countries but many countries' governments in Africa will use French as the official language meaning the statistics are not easily available to the researcher.

In fieldwork there will be the challenge of a possible language barrier between the researcher and the research participants. In urban areas of Ghana and Malawi it is expected that research interviews will be able to be conducted in English, however there could still be misinterpretation of certain words and phrases. In other scenarios, it may not be possible to conduct the interviews in English, and a translator may be required. From the author's experience working on a research project in Malawi where the lingua franca was English, talking to farmers from rural areas still mostly required a translator who could speak the local language. Using a translator for research placed a large emphasis on their role, where the interviews with farmers were translated by a former government worker in the department for agriculture who had a strong friendship with the leader of the charity we were working with. For example, on interviewing farmers after having used our pumps we asked how they found using the technology and the translator gave the answer *'yes, no sweat to use it'.* In actual practice one of the farmers had found trouble using the pump and had, instead of pedalling, got off and used his hand to turn the pedals to power the pump. This is a possible example of bias where the research participant or the interpreter is looking to give the answer the researcher wants to hear.

It is recommended to aim to learn some of the local language for a research project, as this can help to build relationships and gain better understanding (Scheyvens, 2014). A small knowledge of the local language will be able to help the researcher if working with an interpreter as the researcher can get a sense of whether participants are deviating from the questions or there is misinterpretation (Scheyvens, 2014). The challenge of using an interpreter and the results collected has been identified in previous work and in other research where the interpreter can possibly act as a filter on the information (Watson, 2004). To minimise misinterpretations and influence of the translator perhaps affecting research it is key to therefore ensure that the translator provides as literal a translation as possible, only providing input at points where the phrase may not have a direct translation (Furber, 2013). This is a key point to agree with any potential translator before beginning research to also ensure consistency.

3.2.1.2 Models for Understanding Culture

To successfully carry out social research, and potentially implementing technology that could change how people go about their everyday lives, an understanding of the culture and its implication to the research is required.

There are a number of frameworks for researching and understanding culture available which look at patterns of meanings in different cultures (Geertz, 1973), different dimensions of culture (Hofstede, et al., 2010) and paradigms (Schein, 1985).

Hofstede's model of six different dimensions to national culture is probably the most influential framework, and is selected as the model of culture used to inform this research. It provides a concise way of getting to grips with how different cultures vary, and provides a good explanation for some of the author's previous experiences of different cultures. This model was based upon the responses to questionnaires by IBM employees, which were used to find six different dimensions of culture where answers would vary across different countries. The responses were then analysed and factored to give a range from 0 to 100 for the countries of study measuring how much a country applied to each dimension. This score is only a representation of how each country answered relative to another (Hofstede, et al., 2010).

The extent to which it has been verified by other studies investigating culture, and how the studies have been repeated and updated from 1980 through to 2010 (Hofstede, et al., 2010) provide a reliable model to understand cultural differences between the country of the author and the country of study. Whilst this model is a useful tool, it must be understood as only an average measurement of how national cultures compare to each other, and is not a holistic description of all the people that will be interviewed. Hofstede himself noted in his first book that the dimensions are only constructs, and they are only used to help understand a complex phenomenon (Hofstede, 1980). It must also be recognised that often nations are constructs with huge variations in political, social and historical context so trying to understand culture at a national level can only ever be a guide. Instead it is only an initial idea of how aspects of the researchers own patterns of thought and interpretations may only be a product of the culture in which he was raised. The values and differences identified by Hofstede are used instead to predict the sort of differences that might be expected in the values and culture of the community of study to enable success of the social research and planning community sanitation systems for the future.

Hofstede's model of culture looks at differences in 6 aspects of national cultures that can be quantitatively analysed. The six components are: Power Distance Index (PDI), Individualism, Masculinity vs Femininity, Uncertainty Avoidance Index, Long Term Orientation and Indulgence vs Restraint. His work identifies large differences across cultures from the UK to research countries of Ghana and Malawi showing that there may be issues that can have largely different meanings in communities that are being researched.

Whilst Hofstede's work is very influential in terms of providing an understanding of cultural shifts that can be observed between states, it still only provides an understanding of culture on a macro scale. When researching how applicable urban sanitation solutions are there needs to be a deep understanding of the local context and the day to day lives that can be hugely variable in circumstances such as moving from cities to rural areas and wealthier to poorer areas. For this reason, the research needs to be grounded in a deep understanding in the local realities to really understand how engineering solutions interact with people. This places more emphasis on aspects of research mentioned in Scheyvens (2014), such as developing enough links and language to get a greater understanding of the local realities being researched rather than focusing on broader patterns.

3.3 Social Research Approach

There is a wealth of literature guides providing an overview of the process of conducting social research, which can be applied to the aims of this research to define a method. Denscombe (2007) provides an overview of the different strategies and methods available and their benefits and how to use the methods. This does not cover the considerations of the researcher's paradigm and how this can influence the design of the social research. Robson (2012) provides a more thorough overview of the research process from choosing the question through to choosing the methods and then analysis of results. Neuman (2014) also provides an overview of the differences between qualitative and quantitative approaches to social research, however this sees the two as opposed and incompatible methods. This is not a view with which the author agrees, as the research may require quantitative and qualitative data depending on the question, so Robson and Denscombe are used more thoroughly as they give an overview of the use of mixed methods. Further to the general social research guides Scheyvens (2014) provides a context of how different social research methods apply in a development work context, giving specific attention to experiences and challenges such as the language barrier likely to be experienced or issues of power difference between the researcher and the researched. There is further literature to be found with regards to how different strategies and paradigms are used in related fields in Sub-Saharan Africa, to look at how methods can work in practice.

3.3.1 Research Paradigm

Social Research can be framed through different paradigms, which Neuman (2014, p. 96) defines as:

'general organizing framework for theory and research that includes basic assumptions, key issues, models of quality research, and methods for seeking answers.'

As the paradigm of the researcher will influence the approach and methods taken towards social research, the main theories are discussed here before presenting critical realism as the framework. This is considered an important part of the planning process as knowing the researcher's assumptions and making them explicit helps in assessing the findings of the research (Neuman, 2014). For this reason it is important for anyone referencing this research or following on from it to understand the standpoint and assumptions that were taken in the process.

Ontological perspectives of a researcher relate to their beliefs about truth and realities that exist in the world. Epistemological perspectives of a research relate to how knowledge and understanding of these realities can be acquired (Robson, 2012). The epistemology of the research is closely tied to the ontology as different beliefs about knowledge and its nature will have different corresponding approaches to obtaining knowledge. There are two different philosophies identified by Moses and Knutsen (2007) as naturalism and constructivism, but rather than diametrically opposed theories they are treated as opposite ends of a spectrum of beliefs, shown in Figure 3-2. These theories are also known as positivism and interpretivism by different researchers (Sayer, 2000). This subsection assesses the different philosophical perspectives and makes a case for a critical realism approach.

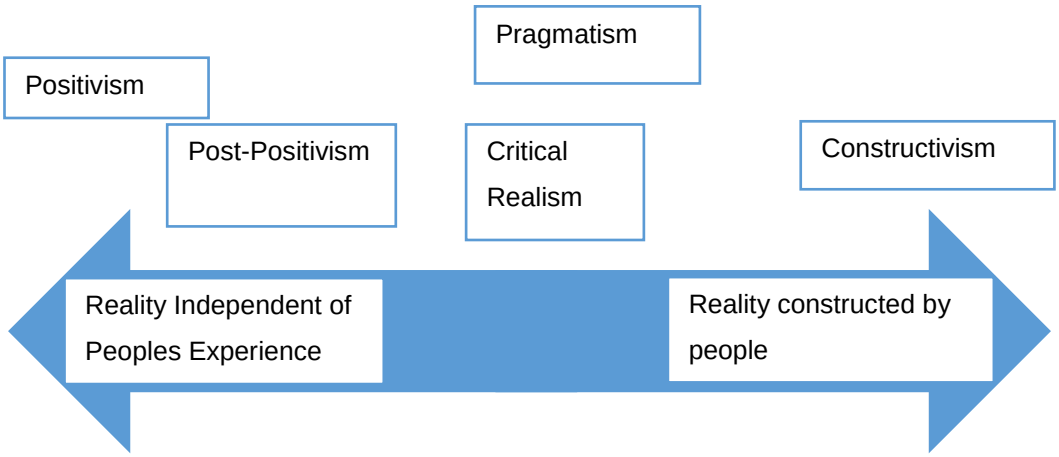

Figure 3-2: Spectrum of Ontological Standpoints of Research

3.3.1.1 Positivism

Positivism, which is also referred to as naturalism in other literature, is used widely in social science and applies the scientific method and model to social research (Neuman, 2014). In terms of ontology positivism believes that there is a real world independent of people's experiences and interactions with it (Moses & Knutsen, 2007). The positivist view of the world is that there are observable patterns, as in natural sciences, and universal causal laws that can be tested and investigated (Robson, 2012).

Epistemologically, Positivism is closely linked with quantitative research of social phenomena, as the use of qualitative analysis of people's opinions does not really apply to a framework of thought believing that objective knowledge is gained from experience or observation and assumes people *'looking at the same bit of reality sees the same thing.'* (Robson, 2012, p. 20). Positivism believes the methods of

natural science can be applied to the social world for gaining knowledge through observation and direct experience (Denscombe, 2007).

Whilst positivism may apply as a framework to certain areas of sanitation research, such as the link between untreated waste disposal and water-borne disease, this is an unsuitable paradigm for researching the social aspects of sanitation provision as there are clear aspects of human behaviours and interactions with technology that affect the success of systems and people have been shown to have different interpretations of the same reality. This is not to dismiss positivism as a school of thought but only to say that it is a model of research and approach to knowledge that is not suited to the research issues found in the literature.

3.3.1.2 Post-positivism

Post-positivism arose from criticism of the positivistic approach to social research, including that direct experience is not a good basis for knowledge in social research due to the researcher's own biases (Robson, 2012). Post-positivism differs from positivism in accepting that the researcher and their framework will influence the research results found, and that the full scope of social reality cannot be captured (Sandu, et al., 2012). Instead Post-Positivism believes that *'research is the process of making claims which are then refined or abandoned in the light of evidence'* (Robson, 2012, p. 24).

3.3.1.3 Constructivism

Constructivist theory, also listed as interpretivism, opposes positivism in believing that there is no unique reality to be studied and it is instead constructed by people that see different reality through social and cultural effects (Robson, 2012). Ontologically there is an acceptance that many of the patterns that a social researcher aims to investigate are influenced by human interaction, and constructivism acknowledges the observer and society's role in constructing that are being investigated by the research (Moses & Knutsen, 2007).

The aim of constructivist research is to build understanding through creating constructs of multiple observations, which will usually use interviews and qualitative methods (Robson, 2012). Research attempts to understand actions and patterns in terms of their socio-cultural contexts as opposed to the aim for laws of patterns in positivism (Moses & Knutsen, 2007). Results of constructivist research are only seen as generated realities of the researcher (Mir & Watson, 2001). Instead of

aiming to demonstrate a pure truth or universal law, constructivist research instead is ‘honest and open about the way in which our contexts (and those of our subject matter) frame the way in which we come to understand’ (Moses & Knutsen, 2007, p. 12).

This would be a more realistic model to apply to the research aims than positivism or post-positivism, as it accepts that different people will have different perceptions of same reality which will help to understand issues with acceptance of sanitation technology. This need can be seen in the varying perceptions of using treated faeces in agriculture across Ghana which shows that people’s perceptions of resources will be dependent on their background. People will have different views of the issues with sanitation provision in Ghana based on their role as well, for example public toilets users and owners will have different views of the technology that need to be understood to generate realistic data. Therefore, elements of the research looking at how sanitation is perceived can be viewed through a constructivist paradigm. This paradigm was adopted by Mazeau (2013) in his thesis investigating which models of shared sanitation facilities are acceptable to urban dwellers in Ghana, as the research was investigating individual perceptions of sanitation and so had to accept the different interpretations. In other research there is limited focus on the paradigm of the researcher in literature of different research in sanitation, with more focus on the strategy and methods used.

3.3.1.4 Critical Realism

The philosophy of critical realism stands between constructivism and positivism and aims to combine features of the two (Moses & Knutsen, 2007). Like positivism, critical realism recognises that there is a real world of observable patterns that are independent from people’s experiences and interactions with it (Moses & Knutsen, 2007). The philosophy also shares features with constructivism in that they recognise that there can be many constructed layers of meaning and interpretation with reality (Moses & Knutsen, 2007).

Critical realism believes that there is no unquestionable knowledge and aims to understand underlying patterns that produce social phenomena and events (Robson, 2012). This philosophical approach was taken in a similar case study project investigating water and sanitation projects and their social impacts in rural Ghana (Furber, 2013). In terms of beliefs about obtaining knowledge, critical realism

is a more pragmatic combination of constructivism and positivism as explained by Sayer (2000, p. 19):

'*Compared with positivism and interpretivism, critical realism endorses or is compatible with a relatively wide range of research methods, but it implies that the particular choices should depend on the nature of the object of study and what one wants to learn about it'*

Critical realism is the research paradigm adopted in this research due to the benefits of constructivism, whilst still recognising the need for positivistic engineering data at times for technical aspects of FSM.

3.3.1.5 Pragmatism

The philosophical standing of pragmatism is to apply what works to research, and seeks a middle ground between the diametric opposites that seem to exist in social research paradigms (Robson, 2012). The pragmatic approach to knowledge is that it is based upon world realities, such as the link between waste disposal and disease, and constructed by people's interpretations of these realities, such as not considering latrine emptying a valuable enough service to pay for it (Robson, 2012).

3.3.2 Research Strategy

Choosing a research design or strategy relates to choosing a strategy of investigation that is most suited to the research questions in focus (Yin, 1994). Yin (1994) suggests a model with three considerations influencing the selection of the most suitable strategy: type of investigation question, the control the researcher has over the environment and events and the level of emphasis on contemporary events versus historical events. In a small research project it is vital to identify the correct approach as the level of time consumed can make it difficult to change strategy or method during the project due to time or funding constraints (Denscombe, 2007). There are a range of strategies available shown in Table 3-1 which lead into the selection of methods such as interviews or questionnaires. This subsection looks to assess the different options and how suitable they are for the different investigation questions the research looks to answer and different scenarios they are used in for research, before presenting a case study as the most suitable option.

Strategy of Enquiry	Form of Research Question	Requires Control of Behavioural Events	Focuses on Contemporary Events?
Experiment	how, why?	yes	yes
Survey	who, what, where, how many, how much?	no	yes
Archival Analysis	who, what, where, how many, how much?	no	yes/no
History	how, why?	no	no
Case Study	how, why?	no	yes

Table 3-1: Criteria for Using Different Research Strategies (Yin, 2009, p. 8)

3.3.2.1 Case Study

Case studies focus on a singular case, or a limited number of cases, of a particular topic of interest looking to investigate the processes and events to a high level of detail (Denscombe, 2007). Yin (2009) states that a case study:

'*Involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence*'.

This method is particularly useful when the researcher is studying an environment that they have no control over and are studying it in a real-life scenario (Yin, 2009). The use of a case study is particularly useful in allowing the researcher to delve deep into a particular subject instance, enabling them to discover more detail (Denscombe, 2007). There is a variety of methods of investigation that can be used as part of a case study as it aims to investigate a topic in depth so multiple methods of analysis are required (Robson, 2012). The ability to use different methods allows triangulation of data to check and validate findings of the research. Table 3-1 shows the different criteria for selecting research strategies according to Yin (2009), with case study being a suitable method for understanding how sanitation can be operated as a sustainable business. The research investigation questions comply with these criteria showing that using case studies could be a suitable method.

Two previous research projects investigating sanitation impacts in West Africa chose case studies as the most suitable strategy showing its suitability to this

research (Furber, 2013; Mazeau, 2013). Furber (2013) used two different case studies to look at how engineers can make water and sanitation projects more sustainable looking at community engagement in the design process. This approach allowed in depth analysis of two different community projects, which helped with the aim of the project which was to find out how rural communities felt about their engagement in design process. The length of the project and narrow geographical focus allowed the use of different methods such as group interviews and face to face interviews yielding different results. For instance, there were different group settings in which people would feel comfortable speaking so spending time focusing on the community allowed the time to find opinions of different groups that may have been missed in a set of focus groups or interviews. Another benefit of long case studies is the ability to build relationships and trust with the local community which will enhance the information that people are willing to share. Mazeau (2013) used a case study approach to investigate the criteria for acceptable shared toilets in urban Ghana as it allowed in depth understanding of different perceptions and the social context. The use of multiple case studies was decided as it allows for analytical generalisations and also a greater understanding of the context in which the research is conducted.

The main concern in conducting a case study is the relevance the findings have beyond a specific set of circumstances (Robson, 2012; Denscombe, 2007; Yin, 1994). There is a question as to whether findings in depth in a particular scenario could be applied to another area (Denscombe, 2007). If a case study strategy is to be taken in this research, this is a particular concern for the findings. If the research is to investigate a small urban community in Sub Saharan Africa and the social impacts of sanitation, then there needs to be an assessment of how the results can provide useful information beyond the particular community studied. Conducting multiple cases could be an option, allowing an understanding of the problem in different contexts and therefore identifying the common findings that may be able to generalise.

3.3.2.2 Ethnography

Ethnography is the ‘description and interpretation of the culture and social structure of a social group’ (Robson, 2012, p. 142). According to Scheyvens (2014), whose book focuses on research considerations in development. This research was originally an anthropological research strategy, aiming to provide a rich and vivid

detail of people's lives in societies that are studied. Through long term residence in the community and building of bonds and trust the explanations of behaviours and patterns emerge through observation (Denscombe, 2007). The depth of study is again a positive factor in ethnography with rich and vivid detailing of how people live (Denscombe, 2007), which would greatly influence good sanitation design. There are practical challenges, however with time and financial constraints limiting the ability of a researcher to spend such long times immersing their selves in a community (Scheyvens, 2014). Ethnography methods were used when looking at the Akan people of Ghana and how excreta is viewed in their culture (Van Der Geest, 1998). This strategy helps to give a deep understanding of the culture around sanitation and how it is viewed. For instance Van Der Geest was able to look at the links in Akan language between cleaning the bowels and the words for 'shit' and 'waste' being associated with far more disgust. He also found that there was a link between the perception of cleanliness as a form of morality, which in the context of re-using waste is an insight into households that can be valuable. The question with ethnography again centres on whether the research can have broader applications beyond the study site, and whether the logistical and time requirements for developing languages and links with communities is rewarded sufficiently with a richness of data that other strategies can not obtain.

3.3.2.3 Grounded Theory

Grounded theory is a strategy of research that looks to develop theory from research and investigation instead of using research to test theoretical ideas (Neuman, 2014). This research looks to build theory through the research and is suitable when researching in a novel or applied field where there is little existing theory to build upon (Robson, 2012). The use of grounded theory most commonly links into qualitative building of knowledge from open ended questions, as there is no pre-existing theory to test so quantitative questions are hard to design for this case (Denscombe, 2007). According to Neuman (2014) the objective of studies using grounded theory is to build theory from scratch and only base theories on new data found. Taking this approach of basing theory around new observations may reduce the influence of the researcher on the results. The level to which grounded theory is suitable depends, however, on the extent to which there is pre-existing theory on investigation questions found in the literature reviews and whether there are existing theories that the author agrees with enough to investigate or whether there is no theory to explain a phenomenon being investigated. From the literature

review many papers have been identified covering the issues that the research wants to investigate, but often they have been in different context and there is little literature about the cities of research in Ghana and Malawi so a grounded theory approach may allow the research to be more flexible in the face of uncertainties than basing an approach on literature from different cities or even countries.

3.3.2.4 Survey

Surveys are a method of research that look to take a wide view of the social world at a specific point in time and map out the social world (Denscombe, 2007). This strategy of research usually involves a structured interview of people or a questionnaire to gain quick, short, answers from a large group of people (Neuman, 2014).

Jenkins and Scott (2007) conducted a survey in Ghana to understand the behavioural indicators of households' decisions to invest in improving sanitation. Using a sampling method from professional market researchers in Ghana allowed a nationally representative sample to be selected and questioned giving results and data that can be representative for the whole of Ghana. The main limitation to a survey such as this is that creating a large sample of different households across the country acts as a limitation to the time that can be spent researching individual people so only certain methods can be applied realistically, with structured interviews used in this research. This left areas such as household dynamics beyond the scope of the research, as the research looked at the decision maker for changes in sanitation. The clear benefit is that the results provided have a much broader impact in terms of understanding people's decision process when looking to invest in sanitation technology and getting statistically interesting data about what are the most important factors in decision making.

Surveys were also used as a research strategy by Katukiza et al (2010) looking at selecting sustainable sanitation technologies for Bwaise III, an urban slum in Kampala, Uganda. The use of a representative sample from the different areas within Bwaise III allowed the research to focus on an area with a population of around 15,000 people. The limitations are again similar to Jenkins and Scott in the need for broad study can reduce the depth of investigation. When engaging community in design focus groups were set up to compare pairs of technology options and select the preferred option until a favoured technology is identified.

This strategy may be suitable to the research looking at sanitation providers depending for more quantitative data at a broader scale but is likely to lose some of the dynamics that can be influential in sanitation systems operation. It is likely that the research will be looking to build a more detailed understanding of the environments that small scale sanitation providers work in and their social context so a survey may only be suitable as an approach for answering parts of the research question or providing quantitative data to also corroborate qualitative data on a larger scale.

3.3.3 Data Collection Methods

This section reviews methods that researchers can use to collect data, and different methods can provide different perspectives on a social aspect (Denscombe, 2007). Different methods are suitable depending on the question that is being investigated, and some are associated with specific strategies (Scheyvens, 2014). There is no reason for the researcher to be locked in by these associations and different methods can be used with different strategies, and it is instead a case of which method suits the investigation (Denscombe, 2007). This subsection assesses the different methods available to a social researcher and makes the case to use mixed methods for the investigation, with different methods being linked to different elements of the research investigation.

3.3.3.1 Interview

Interviews are probably the most commonly known method of data collection and simply involve the researcher asking questions and receiving answers (Robson, 2012). There are a series of different options for what sort of questions to ask and interviews can vary from structured, which involves conducting an interview of set questions with a series of possible answers where the person being researched has very little room to elaborate or develop their thoughts (Denscombe, 2007). Interviews can also be semi-structured or unstructured (Scheyvens, 2014), providing a greater freedom to the interviewee to develop their ideas. Semi-structured and unstructured are not two distinct ideas but more of a range of options as to how much freedom the researcher wants to give to the interviewee (Denscombe, 2007). Unstructured interviews are suitable for research looking to discover and find new information, rather than check existing theories or beliefs (Denscombe, 2007). There are a series of considerations in conducting interviews such as providing simple, unbiased and unambiguous questions (Scheyvens, 2014) and being able to

encourage interviewee to talk freely and openly (Robson, 2012), which could be a challenge on a sensitive topic like sanitation.

Interviews are the most common data collection method used in other sanitation research projects, ranging from structured to unstructured depending on the research aims. Structured interviews, or questionnaires, were used in sanitation research to obtain base-level data about communities relating to households such as toilet facility, number of people per house and age (Mazeau, 2013; Jenkins & Scott, 2007; Katukiza, et al., 2010). Jenkins and Scott's research also used structured interviews when looking at the perceptions of constraints and awareness with regards to making investments in improved household sanitation. The benefit of structured interviews in this context was the ability to gain statistical information about important motivators for sanitation decisions in households from a representative sample of Ghana. The nature of structured interviews also allowed for a larger sample than might be expected with unstructured interviews or other more intensive methods. The limitations come in the narrow approach of the research and it can arguably take the issue of sanitation away from all the other issues in which it sits as an issue for a household. For instance in the results competing needs for household income are a major surveyed response as to reasons for non-adoption but without more freedom to the interviewee it is hard to know whether these are permanent competing interests or temporary issues such as a bad harvest limiting income or health issues.

Semi-structured and unstructured interviews were more commonly used in case study research projects, where there was more emphasis on in-depth understanding of the social context and environment wanted (Furber, 2013; Mazeau, 2013; Diener, et al., 2014). Another element of using unstructured interviews is the allowance it gives for interviewees to offer information that the researcher would not have considered or known, which is particularly relevant when looking at the social environment sanitation entrepreneurs operate in or people's attitudes to sanitation. The limitations of these methods are the opposite to structured interviews, as the requirement for depth can narrow the range of people that are interviewed potentially limiting research to a community or context. The design of closed questions also requires making some assumptions about what the potential drivers or answers will be for questions which may miss new or unexpected ideas.

Interviews are very common methods used in data collection as a means of getting information from a study community and will form the majority of the research for looking at sanitation systems in this research.

3.3.3.2 Focus Groups

Focus groups are another potential option of data collection and can be more efficient than individual interviews as they obtain the views of a group of people in a similar time to just one singular interview (Denscombe, 2007). The other benefit of focus groups is that they can also provide a view into group dynamics in a study group which may provide information for the research as well as addressing the questions (Scheyvens, 2014). For instance, it may allow the researcher a consider the power dynamics in a community group as well as gaining some insight into the research topic. There is also a possibility that a less shy person will enable a focus group to break the ice on a sensitive subject (Robson, 2012), such as sanitation, more than interviewing an individual. There are some limitations to focus groups, however, as it can be obstructed by social power structures and may not truly capture everyone's opinion (Denscombe, 2007; Robson, 2012). Considering the relatively high power difference Index identified in West Africa (Hofstede, et al., 2010), it may be hard to gather a series of different people's opinions if the group composition has people of high influence and power in the community and people of low influence and power. Issues of gender can also affect the structure of interactions in focus groups. A logistical consideration of focus groups is organising a meeting with a large number of people at the same time, and Scheyvens (2014) suggests trying to find a suitable existing meeting.

There can be issues with focus groups, however, if people feel unable to speak in the power structure as identified when looking at community engagement in design in Ghana (Furber, 2013). In this case often the respondents would perhaps answer based on not wanting to disagree with the traditional powerful people within the community, meaning the research often did not obtain the points of view of women. It may still be useful however as a way of understanding how people make decisions and understanding the community dynamics. There is also a chance that people may be more open to discussing issues or ideas in groups rather than individually in cultures that are less accustomed to individual interviews. In Hofstede's analysis West Africa was found to be more collective than individual based in society which may mean the use of focus groups are more suitable than individual interviews.

3.3.3.3 Participatory

Participatory approaches to development research are built upon the work of Robert Chambers, and rather than aiming to purely extract information it looks to empower local participants (Chambers, 2007). Participatory research aims to place the researchers as catalysts for mutual learning through low-technology visualising aids and techniques of research (Scheyvens, 2014). Participatory approaches allow local knowledge to influence results as a wealthy Western researcher is not able to identify and report all the aspects of poverty according to Chambers (1995). In research of urban sanitation in Ashaiman, Ghana, Mazeau (2013) used participatory methods such as transect walks and participatory mapping and ranking of sanitation systems. The use of participatory methods here allowed a better understanding of people's wants with regard to ranking factors in sanitation, which is an example of participatory approaches giving information that a European researcher may not have been able to identify as well using other methods. Some criticisms of participatory research remain, as it can place an extra burden on people who already have busy lives and the approach can just work within existing unequal power structures in a community (Scheyvens, 2014). Another problem cited with participatory research is that it may exclude stakeholders who are not part of the community, such as government officials or sanitation businesses (Mazeau, 2013). Another issue found by Mosse (2005) in participatory research was that the terms of 'participation', particularly with regards to gender were increasingly defined by the project in quantifiable terms. This means that the power dynamic between the researcher and researched is still essentially there in terms of the structure but there is perhaps some more freedom given.

3.3.3.4 Observation

Observation is a method of data collection used where the researcher directly observes research participants going about their daily lives to gain understanding of the culture and processes (Denscombe, 2007). Observation can be particularly useful in a mixed methods research as the data can contrast and complement other methods (Robson, 2012). This is particularly of use if looking to verify other methods of data collection, for instance observation may be able to observe the gap between what participants answer in an interview and how they actually act. Participant observation can have time constraints as it requires immersion in the society of study for the researcher, in order to minimise the effect of people reacting and acting differently in presence of an outsider (Scheyvens, 2014). A challenge of data

obtained from observation is the effect that memory and perception can play on recording of observations, with a possible solution being a simple quantitative tally chart of phenomena the researcher wants to observe such as type of toilet used (Denscombe, 2007).

3.3.3.5 Mixed Methods

Mixed methods, also known as multi strategy research, is a relatively new approach of research that combines different methods, using qualitative and quantitative methods, within a single research project (Robson, 2012). Mixed methods is centred on a pragmatic approach where the methods used are chosen based upon the question of investigation, choosing methods that will provide valuable results (Denscombe, 2007). In the context of development field work Scheyvens (2014, p. 66) states:

'*using a mixed methods approach can provide the researcher with space to capitalise on the strengths of each while also mitigating the other's weak points'*

A further benefit of mixed methods is that the different methods can produce a validated response through triangulation of data (Robson, 2012). For example, if the research was aiming to investigate how many times people wash their hands after using the toilet, then observing people as they leave a public toilet might provide another source of data beyond interviews to improve the quality of the data. The use of different methods can also provide a better understanding of the reality being studied through gaining different perspectives (Denscombe, 2007). A key consideration of mixed methods design is that there must be a clear reasoning of why different methods have been used at different stages of the research (Scheyvens, 2014; Robson, 2012). Overall due to the varying research questions and requirements mixed methods is the adopted method.

3.3.3.6 Other Methods

Photography

Photography is a method of providing further information about an area from the research, suggested by Scheyvens (2014) as a potential option for recording visual experiences during the research. This can again provide context for the researcher when writing up and cataloguing research when out of the field.

Diaries

Diaries are a potential option to be used in social research throughout, and they can help to place interviews or experiences from observation in a context that may help understanding when looking back. If regularly kept, they may provide further information beyond a transcript of an interview about gestures and other things noticed throughout. This is a method that will likely be used as part of the research as the author has previously used diaries to record experiences so will use it to provide information about day-to-day experiences.

3.3.4 Researcher Approach

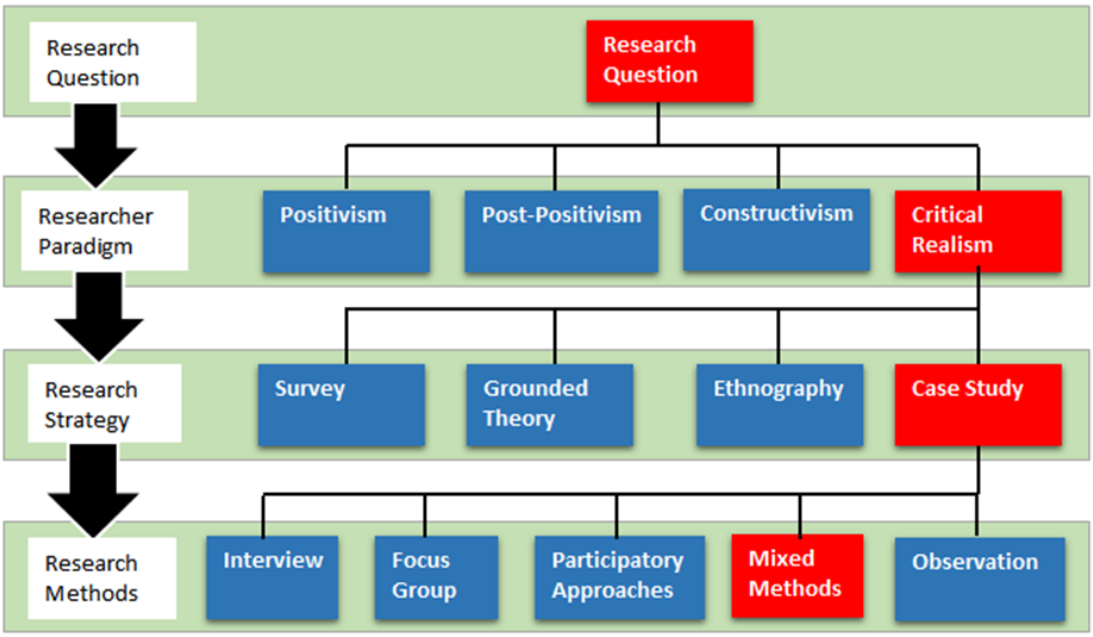

Figure 3-3: Research Approach

Figure 3-3 above shows the approach selected for answering the research objectives of critical realism, multiple case studies and mixed methods. The following section explores and justifies each step.

3.3.4.1 Researcher Paradigm

Critical realism is considered a suitable perspective to approach this research since aspects of the research are 'real world' observable phenomena such as the infrastructure distribution and operational state, but there are also a series of questions that can only be understood through constructing views of other people's realities.

3.3.4.2 *Research Strategy*

A case study strategy was chosen as a suitable approach to the research as it allows for the time and deep focus on a context needed to understand the local context of sanitation perceptions. It is also more suitable to the time and financial resources available than the other favoured option of ethnography. Conducting a case study also allows for the problem to potentially be looked at in different contexts which allows for comparison of the issues with sanitation in different contexts.

3.3.4.2.1 Case Study Locations

A series of criteria were defined for selecting case study locations to ensure the research was successful at investigating areas of gaps in literature:

1. Must be a small city (under 500,000 population) – As discussed in 2.6.2 there is limited research in smaller cities despite accounting for a large amount of the urban population globally and much of projected urban growth
2. English as Lingua Franca- considering the limitations of language observed and noted in 3.2.1.1 it is considered prudent to avoid a double language barrier of working in countries where French is the lingua franca and interviews may have to go from English to French to the local language and back, which would be likely to lose a lot of meaning. Being based in English speaking countries allows the researcher to focus on learning local languages instead of developing French
3. Failing Faecal Sludge Treatment System
4. Limited research about sanitation in the cities- enables the research to fill gaps in literature and also to ensure that it is not repeating questions with research participants
5. Supporting organisation who can assist in the research preparation and carrying out the research

Based on the above criteria two cities were chosen, located in Ghana and Malawi respectively. Sunyani, a city located 125km North-West of Kumasi was chosen as the research location. It was chosen due to the limited level of existing research looking at FSM, the presence of a university for research support and its relatively small size, with a population of 125,000 in 2010 (GSS, 2014). Sunyani is the regional capital of Brong-Ahafo region and 35% of the population are actively engaged in agriculture (GSS, 2014). Figure 3-4 shows the household facilities that are used by the population of Sunyani Municipality. The two major types used are WCs and public toilets. In the urban areas of the municipality the use of public toilets and WCs are even more prominent. From discussions with the supporting organisation in the city it was identified that there were companies providing emptying services with vacuum trucks, there were no reports of faecal sludge re-use being practiced and that a treatment system of waste stabilisation ponds had been broken down for years.

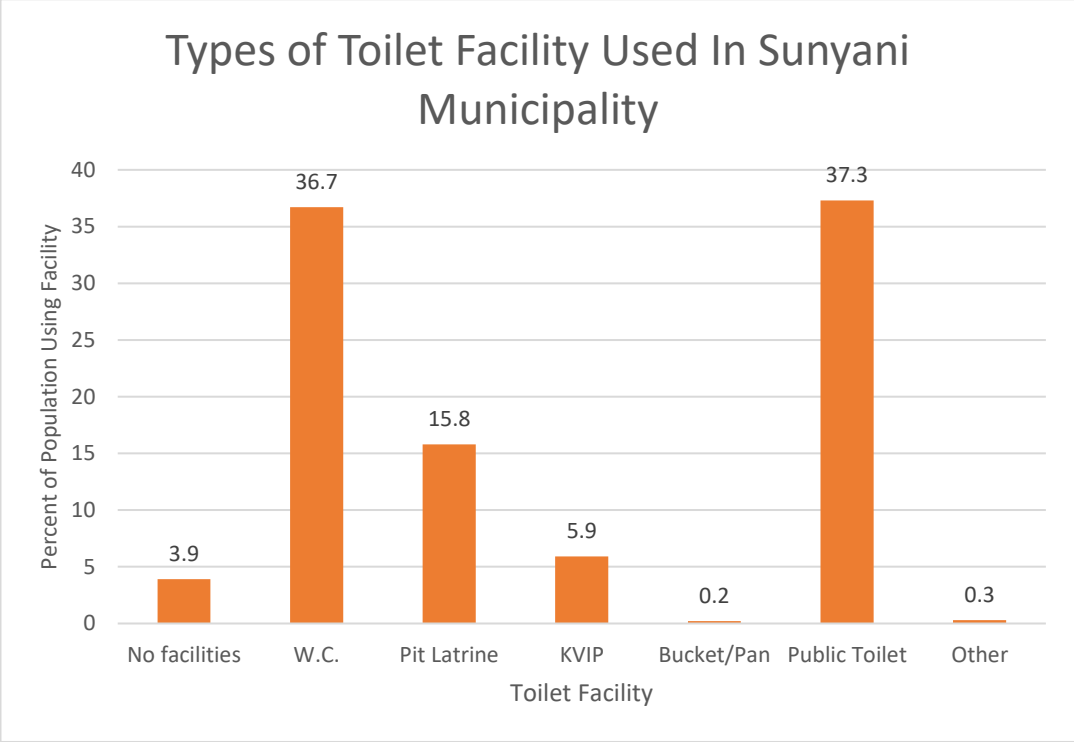

Figure 3-4: Graph of Toilet Facilities used by Households in Sunyani Municipality (GSS, 2012)

Research was conducted in Sunyani between August and December 2015. This research period encompassed the end of the rainy season and the beginning of the dry season in the area. Ethical approval was obtained from The University of Edinburgh.

In Malawi the research case study location chosen was Mzuzu, a city with a population of around 200,000 in 2013 that is expected to grow to over 500,000 by 2030 (Mzuzu City Council, 2011). Mzuzu is the administrative and commercial hub of the northern region in Malawi, with a university and centre of excellence in water and sanitation. Around 50% of the population relies on subsistence farming for income, which is a significantly larger population than the other major cities of Malawi (Mzuzu City Council, 2011). The majority of the population relies on private pit latrines for household sanitation, with around 9.9% of the population using water borne toilets (Mzuzu City Council, 2011). Open defecation was cited as an issue in

Mzuzu. There are a limited number of public toilets in market areas and institutions but they are not used to the same extent as in Sunyani. From discussions with the supporting organisation in the city it was identified that there was one main provider of pit latrine and septic tank emptying services, and a failing treatment site that had been designed for composting but was empty. This was due to the private sector trucks often using sludge on their own farm or farmers in the surrounding areas stealing sludge and applying it on their farms as a form of re-use. There were also projects in the city implementing composting toilets as a form of re-use. Fieldwork was conducted in Mzuzu between January and April 2017, which mostly encompassed the rainy season in the city. Ethical approval was obtained from The University of Edinburgh and the Republic of Malawi National Commission for Science and Technology.

3.3.4.3 Mixed Methods

Mixed methods is not so much chosen as a specific research strategy or methodological approach, rather it is a combination of methods to pragmatically effect that different sub-questions contributing to the overall aim require different methods to be answered fully. Having broken down the overall research aim into questions that need to be answered in each case study, Table 3-2 lists the different methods that are deemed suitable for answering these questions.

Method	Who to Research- how many people?	Questions Applicable	Time	Resources/ People Needed	Analysis	Ethics
Transect Walk	Walk through different communities. Just need a guide/assistant. Not really researching people	1	A few days	Guide Research Assistant	Raw Data: Visual Description on basic map of area Analysis: Write up notes on distinct areas and facilities and append to satellite map Output: Map of different areas of research and features/facilities	Getting consent and guide to take through.
Household Survey	Households in study community	1	2 weeks	Translator Access with communities	Raw Data:Filled out questionnaires from people about what facilities are available and what they use Analysis: Either SPSS or Excel to analyse proportions of people using different facilities Output: Understanding how many people have access to different facilities, providers	Is it something that has been done before and causing more disturbance? Taking peoples time for knowledge that probably does not contribute to field?

Participant Photography	Pit Emptiers- 1 or 2 Community members- 1 or 2	2	1 week	Camera	Raw Data: Photographs Analysis: Ask people which they want researcher to have, why their important, why they took them. Code in Nvivo along with transcribed interviews under different themes to provide further evidence or new themes Output: Photos showing perceptions of sanitation and explanation	Giving ethics training to photographers to ensure there are no non-consented photos taken. Give photos back and allow them to choose what to show.
Group Interview	Pit Emptiers- groups of 8 recommended Community Members	2 and 3	1 hour for interview. Time of transcription likely double normal interview	Filming equipment and Dictaphone Research assistant/translator	Raw Data: MP3/4 recordings of group interviews Analysis: Transcribe data using transcribe software. Analyse transcripts and code using nvivo to different themes Output: coded transcripts for results	Ensuring consent and anonymising of data. Present back findings.
Individual Interview	Pit Emptiers and public toilet operators- as many that serve community Community members-	2	Half/hour per person. Analysis time based on nvivo	Translator Dictaphone Access	Raw Data: MP3/4 recordings of group interviews Analysis: Transcribe data using transcribe software. Analyse transcripts and code using nvivo to different themes Output: coded transcripts for results	Ensuring consent and returning with data. Connection to results through presentation.

Stakeholder Interview	Different business owners/farmers who would be vested in resource recovery. BDS and NGOS supporting small providers	3			Raw Data: MP3/4 recordings of group interviews Analysis: Transcribe data using transcribe software. Analyse transcripts and code using nvivo to different themes Output: coded transcripts for results	
Informal Conversation	All	All	Throughout research period		Raw Data: Notes from conversations with community members Analysis: Type up notes and reconstruct as soon as possible after conversation. Code using nvivo to different themes of findings. Output: coded transcripts of results.	Ensuring that purpose of research is clear and will use conversation and that it is anonymous.

Table 3-2: Data Collection Methods selected for the Sunyani and Mzuzu Case Studies

3.3.4.4 Data Analysis

Interviews were conducted with a translator where local languages were required, recorded and then transcribed for analysis. Transcripts were stored in encrypted folders to ensure protection of information. Qualitative data gained from interviews, photography, focus groups and observation were then coded thematically using Nvivo 11 according to guidelines set out by Robson and McCartan (2016). The process follows five phases of data familiarisation, initial code generation, initial theme generation, thematic network identification and integration. Where possible the processes of identifying themes and coding was done in collaboration with the translator who had been present for research to ensure agreement from both researchers. This process was done iteratively until there is a thorough coding and organisation of the data into themes that fully reflects all the viewpoints and data collected in fieldwork.

For quantitative data from surveys Microsoft Excel® is used due to its ease of use particularly for smaller datasets. This is used to explore quantitative data around household sanitation and perceptions.

For spatial data from observation or transect mapping through either GIS is used for data analysis and manipulation for further analysis and OpenStreetMaps is used for visualisation of geographical features.

3.4 Agent-Based Modelling

Having established a methodology of social research for collecting data about two case cities to look at the potential for implementing resource recovery in sanitation systems, this section explores the application of ABM for modelling future scenarios of socio-technical systems. Due to the limitations of time and finance for fieldwork which make conducting pilots around different management systems for faecal sludge treatment unviable, modelling with integration of social factors provides an

opportunity to look at how social and technical factors interact in sanitation systems and then establish how they could operate differently in the future.

3.4.1 What is Agent-Based Modelling

ABM is an approach to modelling and describing complex socio-technical systems through the construction of interacting individuals with certain rules of behaviour. They are built upon rules for individuals as opposed to mathematical based models of behaviour which assume average properties across a population (Wilensky & Rand, 2015). This added element of agency, when looking at systems allows actors to influence the management and development of technical networks, which in turn affect the behaviours of actors again (van Dam, et al., 2013). Agents can act and interact with theirselves, other Agents and their environment, as shown in Figure 3-5. This approach to modelling allows the research to look at emergent behaviour and potentially predictive modelling of different systems that are grounded in the social phenomena that are observed in both case studies, being able to look at how the social dynamics effect the success of different technical systems.

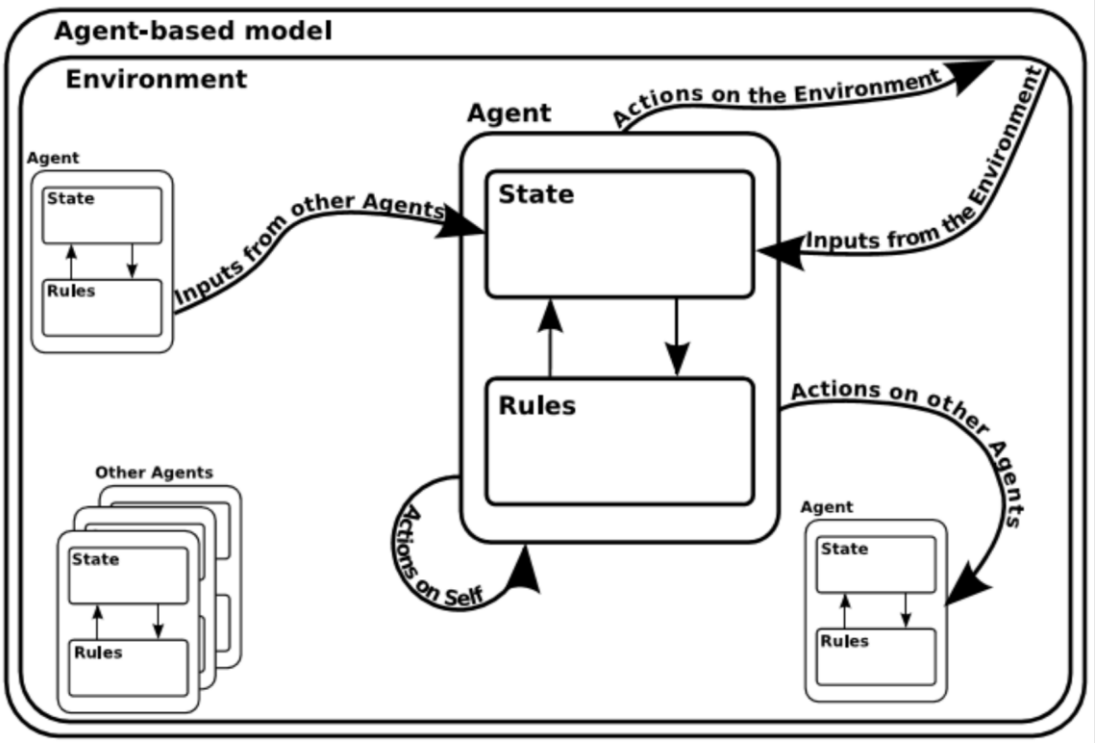

Figure 3-5: Structure of an Agent-based model (van Dam, et al., 2013)

Agents can either be individuals, households or companies or governments depending on the method of simulation (van Dam, et al., 2013). The ability to model agents is particularly useful when the actions of individuals can have a large influence on the study (Railsback & Grimm, 2010). This can be seen as potentially useful when looking at resource recovery due to the elements of technological change that could be required at household level to improve sanitation, and also the role of governments and private sector in managing technical systems. There are models that can be accessed through open source modelling commons to adapt and build, as well as an array of literature looking at different methodologies for building simulations of socio-technical systems.

3.4.2 What Can Agent-Based Modelling Offer as a Research Tool

3.4.2.1 Heterogeneity of Populations

The first potential application that ABM could offer when looking at technological changes in urban areas is that it can incorporate the heterogenetic nature of

populations if looking at adoptions of different toilets or different emptying services. This could take the form of modelling spatial dynamics, for example the likelihood of people to adopt different technologies depending on their plot size and number of rooms, household dynamics such as economic potential, tenure status. Incorporating these into looking at how different technologies are adopted in cities could offer a more realistic scenario and predictor of the potentially complex outcomes of different technological interventions. In an alternative equation-based model where populations are assumed to be homogeneous the prediction of technology adoption could miss important dynamics such as power and influence. For example, it may be of major influence in a community if a church leader does/does not adopt a behaviour, as to how it then spreads to other people, a dynamic which can be explored with modelling individual agents that have different properties.

3.4.2.2 Interactions and Relationships around Technology

The ability to model the individual agents interacting in the context of sanitation operation offers some potentially interesting avenues. As well as being able to model technical infrastructure, it could also potentially explore relationships such as that between regulators and businesses in the contexts of Sunyani and Mzuzu. When looking at issues such as illegal disposal of sanitation being able to understand and model these behaviours could potentially underpin understanding how any future system would operate in reality. Being able to look at and describe these relationships, even in a limited sense, could open up a better understanding of what effects different technical solutions would have on how they are socially managed.

3.4.2.3 *Heuristic Decision Making and Adoption of Technology*

Applying behavioural rules to different agents allows for an acceptance of the fact that humans do not often make decisions based on a rational analysis of all available information. When it comes to modelling consumer behaviour it is clear that humans rarely make decisions with all information or in a rational manner (Banerjee & Duflo, 2012). Again, the creation of behavioural rules can allow for some of this complexity to be explored and accounted for. For instance, if looking at the management of greenhouses an equational model would perhaps be assumed as an optimal convertor of resources into output with no variation but accepting the heterogeneous nature of populations and the varying context could perhaps allow for more accounting of varying soil, varying methods of making decisions.

3.4.2.4 *Inexpensive Exploration of Potential System Solution*

Having collected data looking at the potential for different resource models to be implemented in the different case studies of Mzuzu and Sunyani, ABM can offer a way to predict and simulate the performance of socio-technical sanitation systems identified. This will be done with the existing data that has been collected and using free open-source software it could be a relatively inexpensive method of building upon research data to simulate potential changes without pilot projects and before implementation. Trying to model the more complex dynamics may also highlight the key areas that would influence the success of different models to inform further research before conducting expensive pilots.

3.4.3 Potential Limitations of Agent-Based Modelling

3.4.3.1 *Creating Models of Human Behaviour*

The benefit of being able to model individual agents and their interactions when looking at systems management could also potentially be a limitation to the application of ABM. Having designed a research methodology to capture the complexities of managing sanitation services and systems in two case studies, the

possibility for exploring these complexities on a bigger scale or in different scenarios using modelling could be difficult. Taking Railsback and Grimm's (2010) definition of a model as a purposeful simplification of a system to solve a particular problem, the level of simplification has to be considered. Taking output data from research that will be highly thematic and heterogeneous depending on interviewees and codifying that into rules could perhaps oversimplify certain aspects of behaviour. In the most extreme cases there may be aspects of behaviour that the social research methodology is unable to capture, and that therefore does not get put into a model of behaviour for understanding how systems would work.

3.4.3.2 Path Dependency of Behaviour

Due to the scope of complex systems to which ABM is being applied, the importance of input data is vital (Wilensky & Rand, 2015). This is particularly relevant in models where emergent behaviour is dependent on other actors, for example in the network spread of a virus or the adoption of an idea. This aspect of ABM means that there could be a 'butterfly effect' of sorts where depending on initial conditions there can be highly different phenomena that emerge from interactions (Wilensky & Rand, 2015). This tendency towards feedback behaviour and emergent phenomena could place extra emphasis on the basic modelling constraint that bad data input creates bad results.

3.4.3.3 Validation of Models

To maintain the value of building a model to explore sanitation, or any socio-technical system, using agent-based methods requires validation to demonstrate that the model is effectively simulating a real-world problem. This process of validation can assess how well the model represents actual behaviour observed in case studies at a micro and macro level (Wilensky & Rand, 2015). This is applicable to modelling complex management of sanitation systems, and any model projecting

different technical solutions would need to start with a grounded model of how managers behave, but also the macro level reflection of how treatment plants function in the case study. One issue with this validation process could be the limited functionality of treatment plants across Sub-Saharan Africa found in literature (Strande, et al., 2014). The lack of function may not be a very detailed macro-level function against which to validate any model of sanitation systems, if the only requirement is that it must show failure. The structure and requirements of modelling for different case studies will be highly dependent on the findings of the research, though these issues must be considered when building models particularly when the purpose is to predict future behaviour.

3.4.4 Applications of Agent-Based Modelling

The structure and application of ABM for sanitation would be dependent on the data and interactions observed during research collection. The process of defining and running ABMs is shown in Figure 3-6, and whilst the initial stage of formulating the question has been defined the structure and elements of the system will be dependent on the results of the case studies. Even without having a clearly defined model structure, there are a range of models and cases of applications that could potentially be relevant to looking at socio-technical change in infrastructure systems.

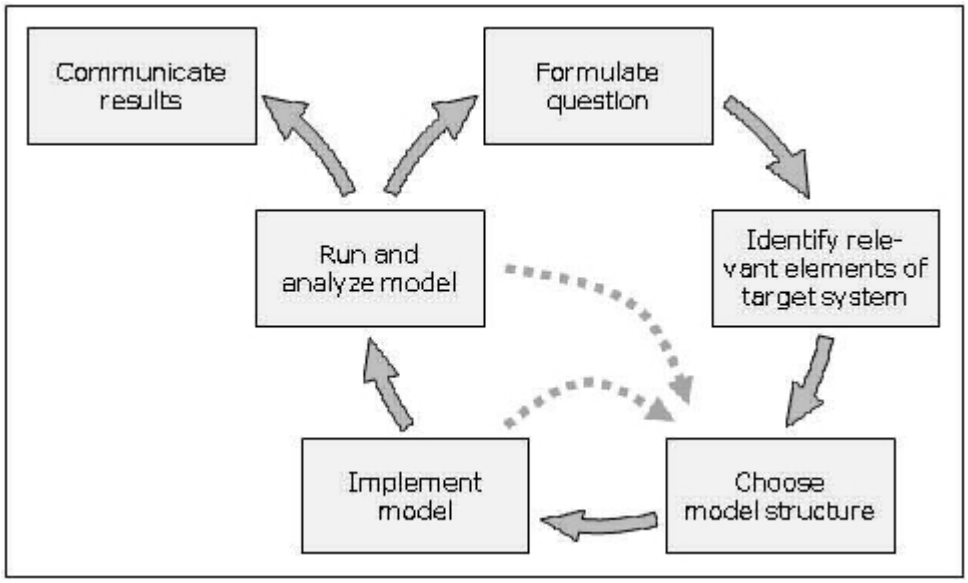

Figure 3-6: ABM Process (Railsback & Grimm, 2010)

3.4.4.1 Transition from Centralised to Decentralised Sanitation Systems

The most prominent example of ABM that could be applied to case studies of resource recovery in Sunyani and Mzuzu looks at transforming sanitation infrastructure in East Germany (Panebianco & Pahl-Wostl, 2006). Looking at transitions from centralised sewerage systems to small-scale decentralised technologies in wastewater treatment, it sets the case for modelling and the implementation of human aspects into modelling and design:

'technology is only the "hardware" and it is becoming increasingly obvious that the "software", the social dimension, has to become part of planning and management processes.'

Looking at the issues of sewerage treatment, the paper sets out a framework to assess how the spread of Ecosan technologies could be modelled. This is potentially applicable to the spread of resource recovery in Sub-Saharan Africa where Ecosan facilities have been promoted as a decentralised sanitation option with less need for emptying and the potential for reuse in agriculture (Tilley, et al., 2014; Chunga, et al., 2016). Figure 3-7 and Figure 3-8 show the suggested framework of potential models of behaviour that could be used to look at the adoption of Ecosan technologies in East German communities.

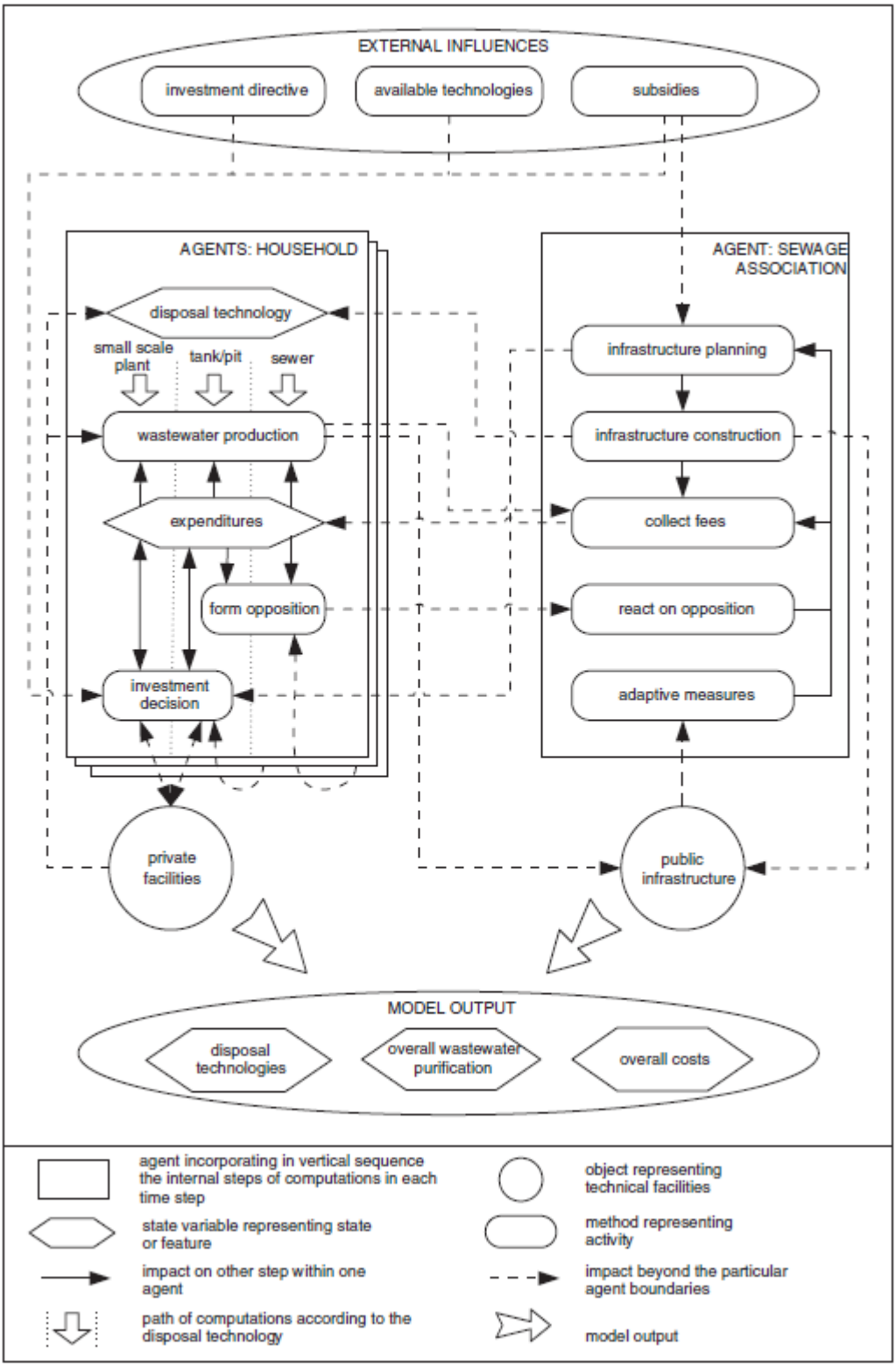

Figure 3-7: Framework for Model of Adoption of Different Wastewater Treatment Technology (Panebianco & Pahl-Wostl, 2006)

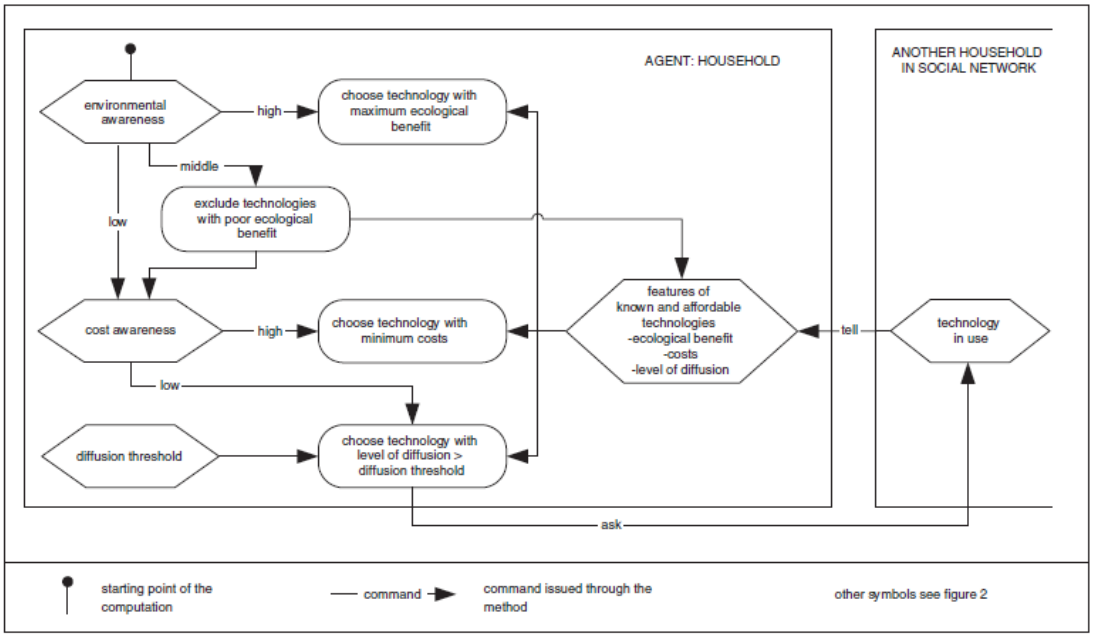

Figure 3-8: Agent Process for Adopting Technology (Panebianco & Pahl-Wostl, 2006)

Panebianco and Pahl-Wostl (2006) builds upon the theory of diffusion of innovations and lock-in by Rogers (1995) to suggest how the transition from the system into which people are currently locked could be changed over time. The aspect of lock-in could be particularly prevalent in systems such as public toilets, for which it is shown that there are political interests in maintaining the current system (Caplan, 2010). The main objectives of the model are to advance learning about the behaviour of systems, uncertainty of problems and how the system would react to different management options. Whilst the paper presents the potential applicability of ABM to exploring the human aspects of technological change, it fails to build upon the work and present results from modelling and validation processes to show the actual applicability of the framework to real world problems beyond a theoretical level. Another consideration from Panebianco and Pahl-Wostl (2006) is the planned modelling time of 30-50 years for predictive modelling. This makes sense due to the slow progress of transformation of technology due to inertia and technological lock-in. The downside of modelling over such long timescales is that realistic external political influences cannot be modelled or understood, such as large shifts in

economics, populations or climate. Depending on the type of technology and institutional model this may be less applicable to looking at sanitation in Ghana or Malawi. For instance, if projects are being implemented by development organisations or NGOs it is unlikely that projects will last this long. Referring to Figure 3-6 the paper only carries out the first three stages of the modelling cycle of identifying the question, relevant elements and structure of the model, without the stages of applying the model and refining it. The principal framework of the model could be a useful basis for starting to look at sanitation system transformations in Mzuzu and Sunyani, but part of the modelling process will have to be to advance the model through generating results and validating them against real world data to further explore the usefulness of the tool in modelling socio-technical systems.

3.4.4.2 Agent-Based Modelling of Government management of infrastructure

Another research paper explored ABM of management of infrastructure assets in technical systems (Osman, 2012). The paper sets out a framework for interactions of actors and infrastructure components in Figure 3-9. This moves beyond traditional infrastructure asset modelling by attempting to capture complex practices and behavioural patterns linked to asset management. Osman showed the potential for ABM as a modelling approach for infrastructure systems as it can model:

- Interactions between users/managers and deteriorating infrastructure
- Politicians setting budgets for management
- Users complaining about services and different mechanisms for feedback i.e. a large business using electricity vs a poor area
- Effects of users on infrastructure as opposed to a stochastic or statistical model of breakdowns
- Feedback mechanisms of people responding to system state and satisfaction

Beyond this ABM also allows for modelling of why/how politicians and operating staff choose to intervene. Osman envisaged the agent interactions in a system of managing water pipes as shown in Figure 3-9:

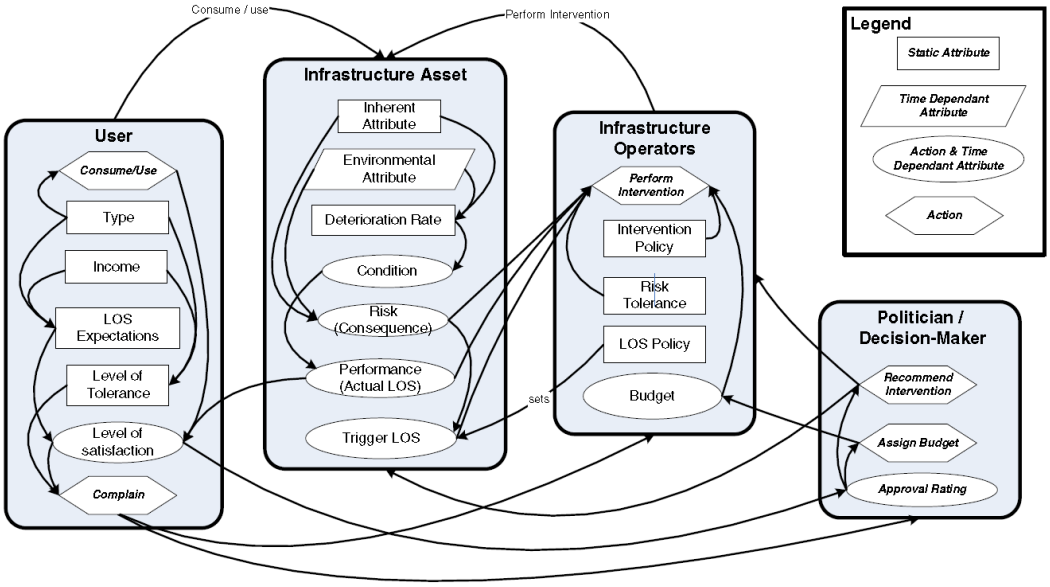

Figure 3-9: Agent-Based Modelling Framework for Infrastructure Management (Osman, 2012)

Osman (2012) introduces a Level of Service theory for looking at utility infrastructure use as opposed to adoption of technologies observed by Panebianco and Pahl-Wostl (2006). This theory complies more with how consumers may behave when using services that they expect such as water or sewerage, but perhaps does not apply to more infrequent use of emptying services or latrine building in Sub-Saharan Africa. The model moves beyond Panebianco and Pahl-Wostl (2006) by attempting to apply the modelling approach to road infrastructure management in a Canadian city and comparing the results produced. Applying a stochastic decision process and agent-based approach yielded similar spending of projects but the agent-based framework produced better service in asset management suggesting a reactive budget-setting and maintenance approach could be more effective. This model is not validated against data from the Canadian city, but simply uses it as a way of observing the differences in the two modelling approaches and the implications. In

terms of actually modelling how infrastructure is managed it is not clear which is closest to reality in terms of understanding how infrastructure is actually managed. A workshop was held with the Cairo Water Company, who are responsible for managing 7000km network of water pipes, to look at how the use of ABM is perceived by stakeholders who would actually use the decision tool. Whilst they believed that the integration of social factors into the modelling instead of modelling them as externalities was useful, they thought the main time constraints may relate to refining the behavioural model of Agents particularly with larger stakeholder groups.

The paper explores well the potential to further understand and simulate the decision processes that could help improve infrastructure management. In the context of looking at sanitation infrastructure, particularly treatment systems, that are not maintained this is a potentially interesting application of ABM. Again the research is relatively limited in setting out a data collection process and modelling process to fully build validated models of infrastructure management behaviour, and this is listed as the main concern of potential users who are in charge of managing infrastructure. The main difference that could inhibit the realism of models here is the role of agents such as infrastructure operators. In the previous model looking at adoption of technology there is a larger number of agents who may adopt technologies for different reasons, whereas in the context of the research reported, infrastructure could often rest on the decisions of one or two agents in charge of sanitation. These agents could also change according to election cycles which may make modelling the decision processes of individual managers more complex. A series of behaviours and interactions that the existing model of infrastructure modelling does not capture but that could emerge in the context of sanitation are listed below:

1. Large donors and their influence on politicians' motives
2. The inherent knowledge of politicians and building knowledge/experience for operators which is particularly pertinent with an electoral cycle leading to turmoil and large staff turnover

3. A privatisation-based model when a business is operating treatment and the different ways that businesses would interact with customers and how this affects their budget.
4. How customers become open to change to new resource-based products
5. Whether level of service expectations that lead to complaints for treatment are much lower due to the 'invisible' nature of the service and whether this also explains part of the failure in infrastructure and why there is a need for a new accountability incentive
6. Whether politicians and managers have other interests beyond sanitation.

Applying this modelling to look at the management of sanitation infrastructure could be difficult in the context of understanding relationships around management and political decision making. When looking at the complexity of public toilet contracts in Ghana for example (Caplan, 2010), there are many layers of competing interests that lead to the existing management of structure. Understanding these complex interactions enough to realistically understand the human elements of sanitation management in Sunyani and Mzuzu could require quite long-term studies with observation that may be beyond the scope of my research. It also runs into the problem discussed in sections 4.2.5 and 4.6.2 that if infrastructure has previously deteriorated to the point of non-operation then it may be hard to look at the interactions and behavioural factors that led to this. These aspects of complexity could also be the exact reason for using tools like ABM, as it can allow modelling of agents with complex behaviour rather than simple technical modelling of systems that have often fallen into non-operation. However its success and application would be dependent on the quality of data that could be generated.

3.4.4.3 Diffusion of Innovation

Beyond the paper looking at diffusion of innovations in networks in East German sanitation (Panebianco & Pahl-Wostl, 2006), there are a series of papers that focus more broadly on the question of diffusion of innovation and adoption of technologies in networks. Looking at different papers provides different structures for modelling networks of people, how different decisions about technology could be made and how to validate different models against observed behaviour. Looking at all these possibilities for structuring models can help to provide different frameworks for how adoption of different technologies may happen in sanitation systems in Sunyani or Mzuzu.

‘Diffusion of Innovation’ theory provides a model of how a new product can spread through existing social networks. This is particularly important for looking at selling resources to consumers in small numbers, or technological transformations dependent on change at household level as to make a profit the product must begin to spread through the population. Understanding the structures and interactions of social networks can have a large effect on how/whether an innovation then spreads through the population (Bohlmann, et al., 2010). For example, modelling social networks as random networks where any two people have an equal probability of being linked compared to a clustered model that accepts two people with a mutual friend are more likely to be linked had significant effects on the spread of an innovation in a study. Along with choosing how to model person-to-person interactions, there also needs to be an assumption of the inherent value of the product which also affects people’s decision to adopt. An element that seems to be absent is the possibility for people to have a bad experience and to exhibit how this could spread through a network. For example, if a key member of a community was identified for an early trial of biogas and there were some teething issues, it would be quite easy for the member to switch back to petroleum-based gas and to inform his social links, so spreading the negative effects.

Beyond Bohlmann et al (2010) looking at the effect of structures of social networks on the modelled spread of the same innovation of same value, illustrating the importance of model structure, Berger (2001) looks at spatial-based models of agricultural options being adopted in Chile. Being able to build and calibrate the model towards micro-level behaviour and macro-level land use allows the model to potentially investigate different technical and policy scenario effects. The model is able to implement hydrological factors and economic factors into simulations of farmer behaviour in adoption of technology, though the author questions the predictive capacity due to their limiting assumptions about human behaviour rather than technical parameters though it still has the potential to be used for policy advice when models can be expanded.

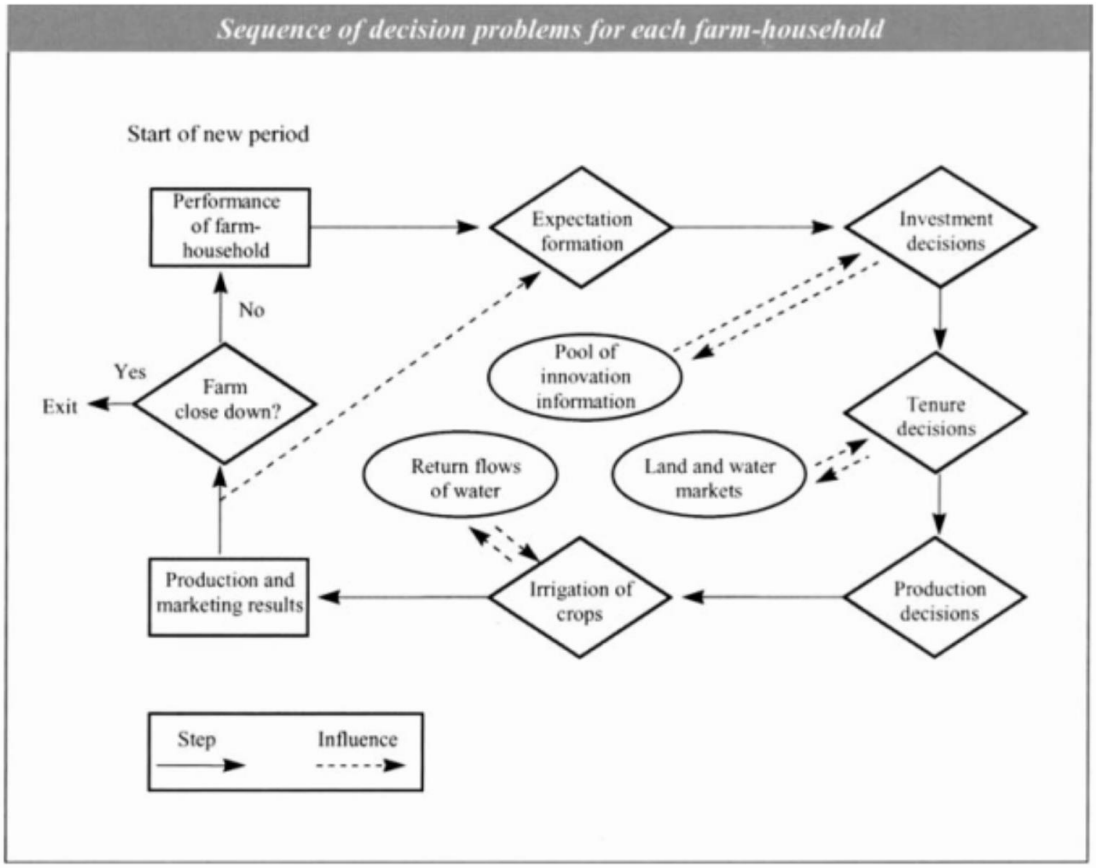

Figure 3-10: Decision Processes of Farming Households in Agent-Based Model (Berger, 2001)

Another adaptation of the diffusion theory was presented by Rai and Robinson (2015), looking at city-scale adoption of solar technology in different policy scenarios. The main benefit of this study is that it has macro level data for validation of the model to conform to adoption levels of solar power in a city. As shown in Figure 3-11, the adoption process of households has two thresholds of economic viability and attitudinal acceptance of solar technology. Of main interest to the application of sanitation is the attitudinal aspect of behaviour adoption, as economic decision making is relatively open to rational, statistical modelling based on income vs costs. Attitudes of adopters were interpreted from previous data measurements from sample adopters and then geospatial extrapolation across entire populations to simulate the level of acceptance of technology. One limitation of the approach is that the survey from which data extrapolated about attitudes only interviewed adopters, who at the time of low adoption rates reflect a relatively niche proportion of the population. Starting from initial attitudes towards the technology people develop their behaviour through interactions of agents, where in general agents follow a Relative Agreement method that leads to behaviour only being influenced by agents of

similar attitudes. Using city wide adoption data that contains time of adoption, location of adopter as well as the choice to adopt allows for different aspects of macro-validation of the model before moving in to policy analysis. Looking at rebates for lower earners in the area, the model was then adapted to provide predictive effects of adoption at different levels of subsidy for solar energy and the effect of timing of subsidies, finding that if rebates are introduced after a significant level of adoption in the community this improves adoption by lower earners due to the social spread of acceptance. This paper overall provides the clearest illustration of ABM for predictive simulations, due to the availability of adoption data for calibration that allows for validation of behavioural theories and interaction dynamics, and which can then be used to simulate policy changes that effect the personal economic decisions and then also the spread of the idea, due to increased adoption. One of the main strengths of this paper lies in the wide availability of second hand data about solar adoption in the context of a city in Texas, whereas long term data such as that may not be readily available in the case of Ghana or Malawi.

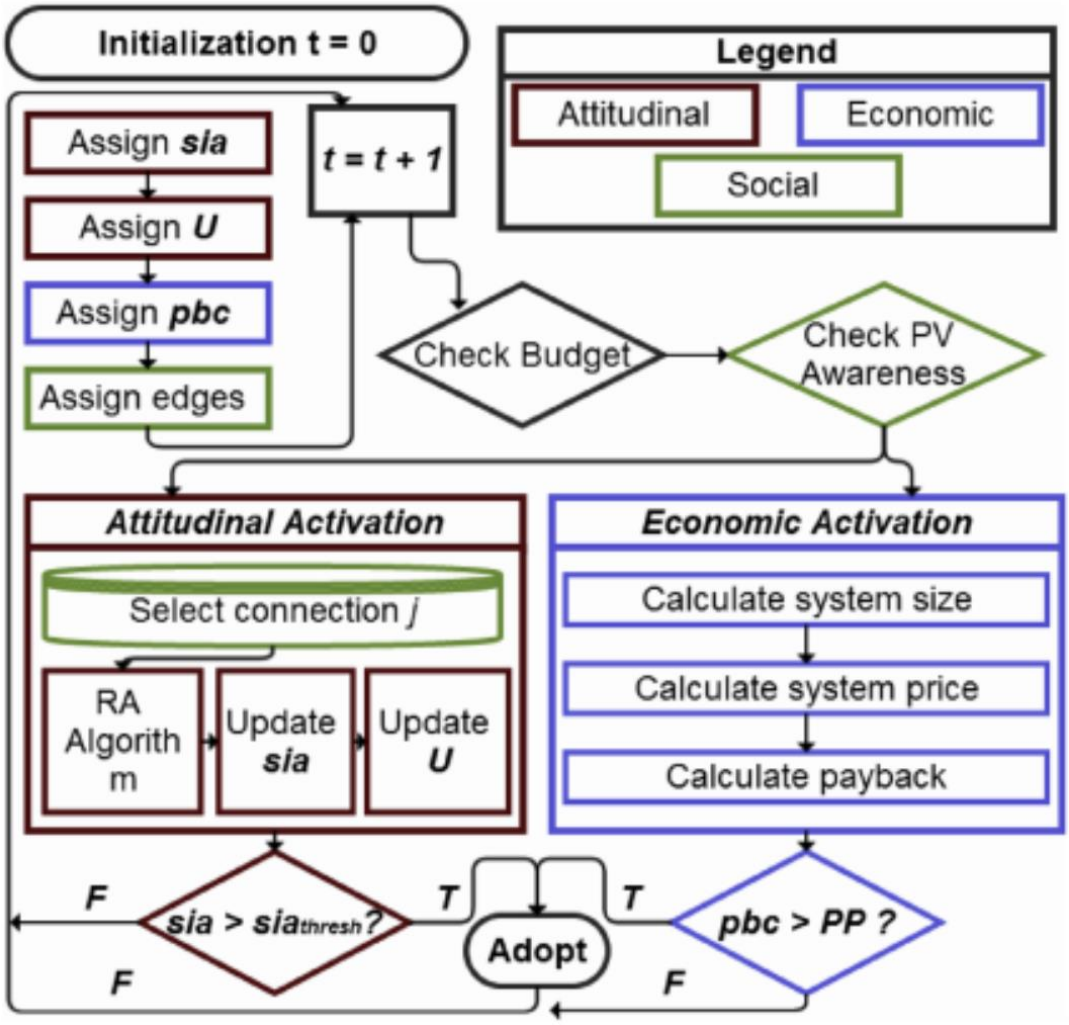

Figure 3-11: Decision Processes of Households Adopting Solar Technology (Rai & Robinson, 2015)

A further theoretical paper offers a theoretical framework for modelling diffusions of technology when there is more than one competing innovations (Laciana & Oteiza-Aguirre, 2014). This paper again offers a potential structure for adoption and behaviour of customers when there is the opportunity to choose between different technologies rather than a binary adopt/non-adopt choice. The limitation of this model is similar to other papers, in that it does not offer a real-life scenario for the model to be applied to.

Delre *et al.* (2010) presented an ABM approach for innovation diffusion in networks looking at the effect of social networks. In this paper the perceived quality of innovations was found to be important and the need to reach 'critical mass' to ensure the spread of adoption was important. In the absence of critical mass and low perception of quality in networks, the social influence becomes considerable,

leading to a relatively slow adoption process. The other aspect on which this depends is how much of an impact social influence has in general in the target markets. It is not clear what level of determination social networks and influence have on markets and attitudes in Ghana and Malawi, and this would need to be considered when modelling networks of adoption based on fieldwork data.

Schwarz and Ernst (2009) look at the diffusion of environmental products in Germany amongst social-networks using ABM. The model of adoption of three different types of technology is of interest, as it is able to use independent data collection as a source of calibration for the model. This is beneficial for modelling in Ghana and Malawi, where data may not be openly available for diffusions of technology to assist calibration and simple methods may be needed. The study uses surveys and questionnaires to assess random households and technology adopters. Surveys and questionnaires may only be useful later in the research process in this case as using surveys and closed questions for adoption theory would require initial assumptions about key categories and questions to ask and may miss aspects that are not considered, therefore adoption will be looked at with unstructured or semi-structured interviews first. The use of modelling in this paper was able to explore the effects of heterogeneous relationships and spatial data, which considering the issues of space for household sanitation in the literature review and varying perceptions of technologies, is likely to be a requirement of technological approaches to sanitation in Ghana and Malawi.

What is striking from the literature is that most research is based around networks in 'developed countries' in Europe and U.S., so there needs to be a consideration of the possibility that social networks in Ghana and Malawi are structured very differently and there may need to be some social network analysis and surveys to get data on a) how people interact and b) the demographics and structure of the larger population to which these trends could be extrapolated, and to what extent it is possible to understand these different aspects. This aspect of behavioural psychology was looked at by Henrich *et al.* (2010) where the study subjects that inform theories about behaviour are often performed on Western, Educated, Industrialized, Rich and Democratic (WEIRD) societies. Looking at jounals in six sub-disciplines of psychology from 2003 to 2007, Heinrich *et al.* (2010) found 96% of subjects were from Western Industrialised countries. One example of where this approach was limited in extrapolating the behaviour of Western subjects to

universality was in the Ultimatum Game and Dictator Game, which measure fairness and cooperation in economic thinking by offering players the opportunity to divide a real sum of money with another player. Replicating these studies with smaller scale societies from different continents found that the Western-based results were towards the extreme end of human behaviour.

Although these limitations may inhibit the usefulness of ABM, the 'glass-box' nature of explicitly stating models of human behaviour with reasoning at least offers a demonstrable model that can be critiqued. For instance, if an explicit model of interactions and sharing of knowledge is grounded in assumptions of psychology that predominantly draw from WEIRD samples, then the modelling still allows for the exploring of these issues and in incorporating human behaviour moves beyond the dichotomy of social and technical literature.

3.4.5 Application/Structure of Agent-Based Modelling for Case Study Results

Having reviewed literature describing the structure and theory of ABM for modelling socio-technical systems, it is considered a suitable enough research tool to explore its potential for predictive modelling of socio-technical changes in sanitation systems in Sub-Saharan Africa. Will its use help to answer the overall research question of 'Can resource recovery ensure effective operation of faecal sludge treatment?' The initial literature has identified potential modelling structures that could be applied to looking at scaling up of reuse in sanitation systems, but at this stage the model has only formulated an initial question. The process of collecting data relating to the research questions will inform the structure and parameters for a model, at which point more models from the commons of open source models available from Netlogo (Netlogo, 2018) are available that comply with the structure and purpose selected. After presenting the case study results in section 4,5 and 6, section 7 will present the modelling process beyond the initial formulation of the question into structuring, running and analysing results. The purpose of the model is to explore the usefulness of the tool itself for being able to simulate socio-technical systems relatively inexpensively, as well as looking at predictive models of different policies and management approaches to sanitation.

4 Sunyani Case Study Analysis

4.1 Section Structure

This section lays out the results from the case study conducted in Sunyani, Ghana. The section is split along the framework identified in Figure 4-1. Questions 1 to 3 are answered before concluding with an overall answer to the potential to solve question 4 separately and then the methods and approach of the research and its implication for the results are reflected on in a reflexivity section.

Figure 4-1: Research Framework for Sunyani Case Study

The methods selected in the methodology were applied in Sunyani, where possible, with the numbers of interviewees shown below in Table 4-1.

Interview Type	**Purpose**	**Number of Interviews Conducted**
Stakeholder Interview	Understand existing sanitation level and challenges in Sunyani	11
Household Interview	Understand satisfaction with existing sanitation and perceptions of biogas and tilapia resource products	34
Farmer Interview	Understand perceptions of fertiliser resource product	30
Fish Farmer Interview	Understand perceptions of fish-feed resource product	4
Business Interview	Understand private-sector engagement in sanitation and economics and challenges of businesses	11

Table 4-1: Interviews Conducted in Sunyani

4.2 What is the existing sanitation infrastructure and who are the providers?

4.2.1 Infrastructure Mapping

From transect walks and site visits it was possible to map out the location of public toilets and the disposal site, shown in Figure 4-2. Sites where LPG gas could be bought were also mapped for comparison with any potential biogas distribution network. In some of the marked locations, there are two or more public toilets in the location indicated.

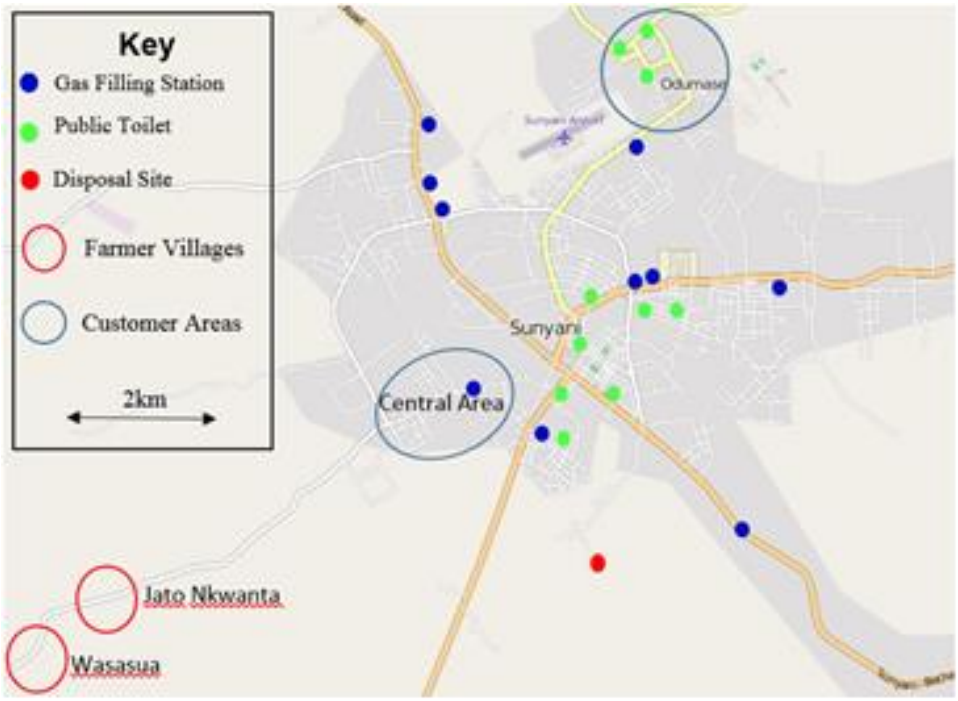

Figure 4-2: Infrastructure Map of Sunyani and Study Areas. Source: Map Data: © OpenStreetMap contributors

Based on the mapping of infrastructure different areas were chosen for aspects of the study. For interviewing customers about sanitation services and the potential for biogas and aquaculture products two urban areas were chosen. Odumase, the first area, is a small town on the outskirts, about 9km from the disposal point, so it was chosen to study the possibility of decentralised treatment. Due to Sunyani's size, it has less of a class division between areas than in the larger Ghanaian cities like Kumasi and Accra, so a central area proximate to identified public toilets and gas filling stations was chosen as the second study area for household interviews. Two farming villages, Jato Nkwanta and Wasasua were chosen for interviews about the possibility of compost use mainly based on the ease of access for research as other farming areas were much more difficult logistically to access.

4.2.2 User Interface

Figure 4-3 shows the household facilities that are used by the population of Sunyani Municipality. The two major types used are WCs and public toilets. In the urban areas of the municipality the use of public toilets and WCs are even more prominent.

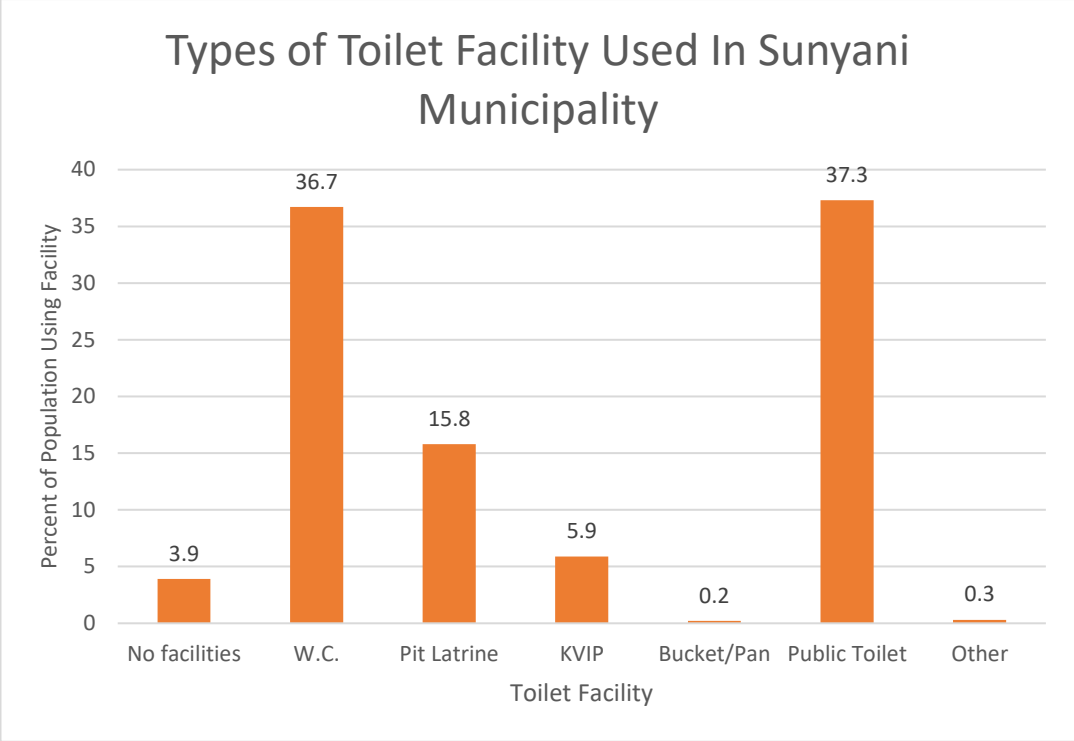

Figure 4-3: Graph of Toilet Facilities used by Households in Sunyani Municipality (GSS, 2012)

Fifteen public toilets were mapped, shown in Figure 4-2. There are a further eighteen public toilets within the municipality but some of these were further away from the city so were more difficult to visit and less central to the research area. The public toilets visited were all privately operated by a mix of local groups, businessmen and local political figures.

4.2.3 Collection/Transport

In addition to the Assembly (local government), there are two main companies who operate vacuum trucks for emptying toilets. The prison service, fire service and local polytechnic also have their own vacuum truck mainly for their own services rather than as a business. Solid and liquid waste is dumped at the same site shown in Figure 4-2. Problems are also often cited with narrow access roads when trying to empty latrines, and the build-up of solid waste in toilets that makes emptying with vacuum trucks difficult. The road to the treatment site is currently very badly surfaced, is unusable during heavy rains and often causes trucks to get stuck.

4.2.4 Treatment

A series of six treatment ponds were set up near to the city centre in 2004, though over time they have become overgrown with weeds and plants, and the accumulation of sludge in the anaerobic ponds has rendered the system defunct. The ponds are currently managed by the assembly, but the landfill site for solid waste is effectively privately managed by the one company responsible for solid waste management in the city.

Figure 4-4: Satellite Images of Treatment System in Sunyani source: Google Earth

It was difficult to assess or observe anything else about the treatment ponds as the area was too overgrown with plants to discern where elements of the system were. When observing with the main trucking company the faecal sludge was dumped at a roadside where it would then pour down towards the ponds, as the original inlet was no longer accessible as shown in Figure 4-6.

Figure 4-5: One of series of treatment ponds at Sunyani that has become overgrown and defunct

Figure 4-6: Vacuum Truck Disposing Faecal Sludge

4.2.5 Faecal Sludge Flows

4.2.5.1 Interview Method

Assessing quantity and quality of sludge in Sunyani was difficult without getting long term access to the ponds for observation and without the local assembly knowing the quantity of sludge being discharged at site. As the trucks were usually of a 10m^3 capacity the volumes have been calculated by multiplying the number of trips that companies say they make to the treatment point by 10m^3. This assumes that the trucks always fill to capacity, which is unlikely. These interview values give an approximate estimate of the amount of faecal sludge being discharged at the disposal site every month, though data from observation would have provided some extra sources of data to triangulate and find a realistic value. This is particularly relevant with Trucking Company 4 where the interviewee did not seem entirely sure of the data and gave an answer significantly higher than other competitors. This may be accurate as they are the company with the most trucks, but the data can only be treated as a guide estimate. It was also impossible to get data about the second trucking organisations disposal trips, as their truck was broken at the time of interview.

Trips per Month	Trucking 1	Trucking 2	Trucking 3	Trucking 4	Total Trips/month	Total Volume/month (m³)
Dry Season	30		30	107	167.00	1670
Wet Season	50				187.00	1870

Table 4-2: Faecal Sludge Flows to Sunyani Disposal Site

4.2.5.2 Potential Sludge Production Method

Considering the uncertainty in the data around FS disposal from the data obtained in Sunyani, an alternative method is to estimate potential flows to the treatment site based on per-capita waste generation. This will be an overestimate as it assumes that all toilets are emptied and safely disposed at the treatment site.

Variable	Septage	Public Toilet and Bucket	Pit Latrine Sludge	Fresh Excreta
BOD (g/cap.day)	1	16	8	45
TS (g/cap.day)	14	100	90	110
TKN (g/cap.day)	0.8	8	5	10
l/cap.day	1	2	0.15-0.2	1.5

Table 4-3: Per Capita Characteristics of Different Types of Faecal Sludge from Accra, Ghana (Heinss, et al., 1998)

The urban population of Sunyani Municipal District was 102,389 in the most recent survey of 2010 (GSS, 2014). This may also account for small urban areas that are within the district but is used as an estimate initially. At the population growth of 2.3% observed in Brong Ahafo region the population would be 120,056 in 2017. Using the percentages of different facilities used from Figure 4-3 the total waste generated can be estimated, as seen in Table 4-4. The overall flows of 50700m^3 per year would be equivalent to 422.5 truck trips per month. This is likely a large over estimate of the amount of sludge that actually gets disposed at the treatment plant, for example bucket latrines would not be emptied using trucking companies. There were also interviewees who did not empty their latrines when they became full, the possibility that sludge is illegally disposed elsewhere, and that people use facilities beyond the one they cite in the government surveys. For example, if people are at work and do not have a private facility there they may practice open defecation or use a public toilet.

	%	Population using facility	l/person/year	l/year	m3/year
No facilitie	3.90	4,682	0	0	0
WC	36.70	44,060	365	16,082,060	16,082
Pit Latrine	15.80	18,969	64	1,212,106	1,212
KVIP	5.90	7,083	64	452,622	453
Bucket	0.20	240	730	175,281	175
Public	37.30	44,781	730	32,689,963	32,690
Other	0.20	240	365	87,641	88
Total	100.00	120,056	2318	50,699,673	50,700

Table 4-4: Volume of Sludge Generated in Sunyani, Ghana

4.2.6 Reuse Options and Their Suitability to Sunyani

4.2.6.1 Biogas

Biogas production from faecal sludge is a technically viable option investigated for Sunyani. There are different businesses in Ghana producing biogas at varying scales from small-scale production at institutes such as schools to centralised digesters run by businesses. The fuels used for cooking are from either Liquefied Petroleum Gas (LPG), wood or coal so the use of biogas could reduce the impact of urbanisation on surrounding woodland. Using biogas to generate electricity in Sunyani would also fill a market gap, as there were regular power cuts in the city with *dumsor,* literally on-off in Twi, being a large political issue throughout the country. In this case a reliable renewable source of energy would be suitable to the context.

4.2.6.2 Fuel

Using dried fuel as a resource was not seen as a suitable option for Sunyani. This is due to the lack of fuel-using industry in the city that would have a demand for large amounts of fuel. There was very little industry of this sort in the city so to sell the fuel to businesses would require transporting to Kumasi. In this case, it would be simpler to start with a faecal sludge to fuel conversion plant in Kumasi with a more proximate supply chain. The potential to sell to small-scale customers for cooking fuel was not considered viable, as often the concern when discussing the use of biogas as fuel was that they would be able to see or have to handle the faeces, suggesting that they would not be open to using dried faeces as fuel.

4.2.6.3 Compost/Fertiliser

The re-use of faecal sludge for agricultural products such as compost or fertiliser was considered a viable option to investigate in Sunyani. There were communities of peri-urban and rural farmers who bought fertiliser at the central supermarket that

any resource-based model would be able to compete with and access customers. There has also been research showing that farmers in the North of Ghana particularly use faecal sludge for their farms (Cofie, et al., 2004), so it was considered of interest to see if this was the case in Sunyani and whether it could possibly suit as a technical solution.

4.2.6.4 Aquaculture

Aquaculture systems based on plants or fish were considered as suitable options to be investigated further in Sunyani. With the broken down WSP systems it would be possible to retrofit aquaculture systems to a rehabilitated system. In terms of raising fish in the final stages of the ponds the species tilapia would be considered as previous research with catfish found that there was often cases of cannibalism and tilapia is another species that could survive low DO conditions without cannibalism risks. Tilapia is also already a well spread dietary option being sold in markets and at restaurants in Sunyani. For aquaculture, harvesting duckweed as an animal feed is the main option considered.

4.3 Which technical options for sanitation systems best serve people's needs and aspirations?

4.3.1 Satisfaction with Existing Sanitation Services

4.3.1.1 Household/User Interface Satisfaction

In Odumase 8 interviewees had private toilet facilities or a shared facility in their compound house, while 11 interviewees used public toilets. In the central area, 10 interviewees had a private or shared compound facility, while four used a public toilet. There was a large contrast in the satisfaction with public toilets between the city centre and Odumase, with people in Odumase citing the public toilets lack of hygiene as causing 'whites':

Me: *Do you have problem with public toilet?*
Interviewee: *Sometimes you can get diseases from contamination and there are also delays when waiting in queue to use.*
Me: *what diseases do you get?*
Interviewee: *Whites.*
Me: *Has it affected you or members of your family recently?*
Interviewee: *yes it effects everyone. The heat from the toilet causes it and closes*

everyone
(Household interviewee, 18-35, female, Odumase)

Me: *Why did you build a private toilet?*
Interviewee: *I do not like the public toilet nearby as it is not cleaned well and can give you whites.*
(Household interviewee, 36-50, female, Odumase)

The problem of whites seemed to be localised to one or two specific public toilets in Odumase, whilst the interviewees in town had no complaints about the disease. This may be down to the fact that the interviewees were based around the location of one or two public toilets, there could be worse issues with hygiene in other parts of the city. The common sources of issues across both Odumase and the central urban areas were waiting times, increasing cost and cleanliness of the facility:

Interviewee: *There are problems. first of all about the way they maintain sometimes they don't clean the place well sometimes you will go and the place will be dirty and sometimes you see the public toilet it is not water closet you go you fetch your own water. so you take your own water and you flush it but sometimes you will go and then people just go and then after they just leave*
Me: Are there any other problems or is that the main issue?
Interviewee: *I think that one but you can also talk about the price because the cost keeps increasing so last year was about 20 pesewas or so and now it is 30 pesewas and I know when I come by next year it will be 40 pesewas so that is another problem.*
(Household interviewee, 18-35, male, central area)

Me: Do you have any problems?
Interviewee: I don't think I have any problems. the only problem is the moment you go there there is a long queue and you have to join a queue so that is a concern also the way they maintain it is a problem so someone will ease themselves and will not flush it so you have to go and get water and flush it yourself.
(Household interviewee, 18-35, male, central area)

For those with private/compound sanitation the major issues seemed to arise from having shared access with toilets often being only for the landlord's family. People also cited issues sharing responsibilities for cleaning, maintaining and emptying facilities:

Me: *Did you ever have private facilities here?*
Interviewee: *No, where we live we're renting from landlord and it's not part of landlords plan to ever build a toilet.*
(Household interviewee, 18-35, female, Odumase)

Me: *So how many people are sharing?*
Interviewee: *we are almost 40.*
Me: *how much does it cost for assembly to empty.*
Interviewee: *I don't know but heard someone talking about it being GHC160-260 to empty.*
(Household interviewee, female, central area)

Me: *Do you use any chemicals to try and keep the level of the tank low?*
Interviewee: *ok the problem is here the water closet is restricted to some people they are only using it it is not everyone in the house using it. I myself don't use it. It is only the landlord, the wife and the children who use it so we the tenants here don't use it.*
(Household interviewee, 18-35, male, central area)

A further issue that arose in terms of a driver for people building private sanitation was that of family disabilities:

Me: *Do you share the facility with other people in the compound?*
Interviewee: *It is only used by us as we are disabled and the young children also use. Adults who are healthy use public toilets.*
(Household interviewee, 50+, male, Odumase)

4.3.1.2 Emptying/Collection Services Satisfaction

Overall customers with private toilets and public toilet operators seemed satisfied with the services available for emptying toilets in Sunyani.

Me: *Do you have any problems with emptying services?*
Interviewee: *Other than cost the problem is that they come as and when they are ready so you may call but they have another contract so they do not come then when the assembly comes they think you've decided not to desludge.*
(Public toilet owner, male)

Me: *So why do you choose to use this provider?*
Interviewee: *They are reliable. The private owners who also do the same business*

but cannot arrive on time. Every month they be coming here asking whether the hole is full.
(Public toilet owner, male)

Me: *Do you have problems with emptying services?*
Interviewee: *Sometimes when you call the company is already scheduled so you can not get them for a few days as they are going to kenyase or they are elsewhere. This is a private company that I prefer.*
Me: *Why do you prefer?*
Interviewee: *They take the time to do the job properly so if they have to add water they will do it exactly as you ask whilst others might just come to do as quickly as possible and get pay.*
(Household interviewee, male, central area)

From observation with trucking companies and assembly services some labourers and workers did not fully protect themselves, with some not liking the protective equipment. The health risks of different treatment models for employees would need to be considered as part of any system, particularly if there is unlikely to be uptake of protective equipment use. For instance in reuse in aquaculture or agriculture there would be an increased amount of handling of faeces which would pose a health risk to the operators if they were not to adopt such protection (Iqbal, 1999).

4.3.2 Demand for Different Resources

4.3.2.1 Biogas

Biogas was a resource option that many research participants were familiar with in this case study, with 14 of the 34 interviewees having some knowledge of the concept of biogas in discussions. It was also the resource that the city sanitation managers were most interested in producing. When the method of production was explained, most interviewees were open to the idea of using biogas if it was competitively priced.

There were some differences between customers in Odumase and town with regard to biogas. Firstly, people in town mostly used liquefied petroleum gas (LPG) for cooking whilst those in Odumase used coal or wood, citing the expense of gas as prohibitive to buying:

Me: *What do you use to cook?*
Interviewee: *Charcoal because the gas is too expensive.*
(Household interviewee, male, 50+, Odumase)

Me: *If you saw available at a market biogas from human waste would you consider using?*
Interviewee: *If I had money and can afford it I would consider.*
(Household interviewee, female, 18-35, Odumase)

Me: *So how much do you pay for coal?*
Interviewee: *It's 1 cedi for 2 days. The wood is also 1 cedi.*
Me: *So why do you use coal not gas.*
Interviewee: *its expensive gas can cost up to 40 Cedis for a cylinder*
(Household interviewee, male, 18-35, Odumase)

This could be due to the upfront cost of canisters, which started at 100 Ghanaian Cedis (GHC100), enough to buy three months' coal. It could also be due to the longer-term costs of using gas with people often saying they used coal when a gas canister was empty. Pralahad and Hart's (1999) work looking at the bottom of pyramid consumers often found the potential for success was in single serve items due to customers inability to save and pay for larger quantities, which would seem to correlate with peoples preferences for use of small quantities of coal or wood rather than gas. This means there might be marketing and innovative approaches required replacing coal and wood with biogas in Odumase and other lower income areas, whereas people in town who already use LPG are an easier market to access. Cost was a major consideration for all interviewees when asked about using new fuels:

Me: *So the research is looking at what people want to know and perceptions.*
Interviewee: *I think it would be a little costy*
(Household interviewee, female, 50+, Odumase)

Interviewee: *We Ghanaians ….like cheap things. So if they introduce that one and it costs less … I think people will buy*
(Household interviewee, male, 18-35, central area)

In Odumase there was generally less openness to the idea of biogas with health concerns cited more often than in town due to the belief that the public toilets heat was spreading 'whites', making the idea of using public toilet faecal sludge for fuel for heat unappealing to some:

Interviewee: *No I've never heard of that (biogas), it sounds like something you could get diseases from which is bad*
Interpreter: *You do not get diseases from it*
Me: *If you saw available at a market biogas from human waste would you consider using?* Interviewee: *No I wouldn't use because it's bad to use from faeces so I wouldn't buy.*
(Household interviewee, female, Odumase)

Most interviewees were still open to the idea of using biogas though, with more concerns about practicalities of use:

Me: *So if you saw LPG and biogas available at filling station what would you choose between the two?*
Interviewee: *I would use the old one because I do not know much about biogas.*
Me: *So the biogas is produced form storing waste and then can be captured in a cylinder and used the same as gas. Due to it being produced from waste it doesn't last as long so maybe half the time but it would be priced around half the price of the LPG.*
Interviewee: *I would need someone to explain to me how to use it, how long it would last and how long it works if I was to buy it. I know biogas is metabolic material so if materials same as old one then I would use it and if it's not harmful it's ok.*
(Household interviewee, 18-35, male, Odumase)

Me: *If you saw available at filling station would you consider using it at all?*
Interviewee: *At the moment it burns people's houses so I would be afraid to use the gas currently but soon I want to get away when I would use gas.*
(Household interviewee, 18-35, female, Odumase)

Interviewee: *Me I've never tested biogas I've tested wood, coal and LPG and it's ok, people need cheap so if its cheap I would test.*
(Household interviewee, 18-35, male, Odumase)

The other aspect that was of interest was the balance of people who would be dependent on recommendations from friends or those who would need convincing by salespeople:

Me: *What are your concerns about using?*
Interviewee: *I do not have any major worries but it would need to be recommended*

for me to use.
(Household interviewee, 36-50, female, Odumase)

Me: *So it's produced by storing the faeces with waste and then as it is broken down it produces a gas which can be used in the same way as LPG. If you saw available would you consider using it?* Interviewee: *If it is recommended by many people we would use.*
(Household interviewee, female, Odumase)

Overall it seems that biogas would have a potential market to sell to in Sunyani, dependent on being able to demonstrate the reliability and safety of the technology and then the spreading of the technology through the right networks.

4.3.2.2 Duckweed

There is an association of 25 fish farmers growing tilapia in the surrounding area around Sunyani, who currently buy their fish-feed in Sunyani market. The fish farmers were spread out across rural areas that were often difficult to access by road transport, so only four were interviewed. With both stakeholders from the local university and the fisheries department and fish-farmers the cost of fish feed was cited as a large constraint to the business:

Interviewee:… *In terms of the business aspects, feed contributes like 60% of the production costs so it's the major part. So anything at all to do with relation to be feed would be an excellent bonus to the government academics and fishing. Yesterday I was having a chat with one of my students motivating her to go into anything relating to feed. This one would be a breakthrough. Our feeds are imported from Brazil, from Israel.*
(Stakeholder interviewee, academic in aquaculture in Ghana, male)

Me: *So in terms of the costs of growing fish what are the big costs.*
Interviewee: *The feed component is the largest cost because a bag of complete feed weighs about 20kg sell it at close to 80 Cedis so if you do the calculation per kg you can see the amount that goes into. So if you do your breakdown it's the feed that takes a lot of resources, the fingerlings don't take much.*
(Stakeholder interviewee, fisheries department local government, male)

Me: *So do you ever have any problems with supply for feed?*
Interviewee: *We don't have problems, sometimes the problem the feed is available but the money is not there. If you have the money you can go to the factory and*

bring back. but because it costs a bag is getting to 80 Cedis. So I think the feed is not all that difficult to get as long as you have money.
(Fish Farmer Interviewee, male)

All of their work was closely linked with the ministry and their use of feed was dependent on advice from the fisheries department of the local government, so any decision or demand to use duckweed would be dependent on support of the fisheries department:

Interviewee: *so I know something about the leaves you are talking about (duckweed), here in Sunyani it's not common its only me using it as of now, I don't know about the other farmers but as for me even I came to the regional boss and told him about it and he encouraged me to keep it because before it was so much on the pond and I decided just to throw it out as I was worried it would kill my fish so I just let the water and let it out but now it's coming back.*
(Fish farmer interviewee, male)

Me: *So if you went there and you saw a different feed available or something new what would you want to know?*
Interviewee: *When we get it we always depend on their advice. You see if you want to bring a new product to the market you can see the fishery department. You tell them the ingredients in the feed how it tastes like these things. In Ghana there's a group who produces poultry feed but they produce fish-feed in Kumasi and we advised them to bring it here so we can test it, so that they can bring more and we buy.*
(Fish farmer interviewee, male)

One fish farmer was not keen on the idea as she had had to remove it from her own pond to prevent it affecting the water quality and damaging their fish, which can happen with a full cover of duckweed inhibiting oxygen diffusion and light penetration (Iqbal, 1999). Overall, for duckweed to be viable it would need to be done through the fisheries department who were open to the idea if they could be presented with data showing its benefits to aquaculture:

Interviewee: *If you are to use duckweed at least you should have some information and background as to what duckweed can do. Vis a vis having knowledge about some farms, not here, using duckweed and the results that they had using*

duckweed specifically maybe on tilapia.
(Stakeholder interviewee, fisheries department local government, male)

4.3.2.3 Tilapia

Rearing Tilapia directly in the tertiary ponds and selling to customers at the market was the least acceptable option to people in the area as a waste-based resource. People were very opposed to the idea of eating fish that would be grown in sewage plants due to health risks:

Me: *So would you have concerns if you saw tilapia produced this way?*
Interviewee: *Now I would have a problem if I see it with my naked eye I wouldn't consume. Even now because most people don't eat dog it's because the dog they eat faeces that is the perception. So I don't think if I see it with my naked eye they are feeding the fish with the faeces when I'm taking it I will not feel happy.*
(Household interviewee, 18-35, male, central area)

Interviewee: *No I wouldn't buy. Please has it been treated.*
Me: *Yes.*
Interviewee: *It is still very difficult for me to eat. From a Ghanaian perspective if you mention to them that it is produced from this they won't accept it. If you rear tilapia are you going to have any side effects*
(Household interviewee, 18-35, male, central area)

Me: *Would you have any concerns about it being grown in the (treatment) ponds?*
Interviewee: *when I'm eating it it will be hard as the perception is there so I wouldn't like.*
(Household interviewee, 18-35, female, central area)

Interviewee: *When people eat tilapia at home they will remove the gut but sometimes with businesses trying to rush and prepare may not happen*
(Stakeholder interviewee, academic in aquaculture in Ghana, male)

An interviewee from the Fanti region was open to the idea as he was coming from the coastal regions where there is often open defecation and sewage discharged in the sea:

Interviewee: *I'm a Fanti so where I come from they have sea and sometimes when we swim and when the waste is taken it is dropped in the sea so I know it happens. These fishes sometimes depend on the faeces and people go to the shore to*

defecate so if I saw I wouldn't be surprised if I saw it to buy.
Me: *So the way it works for these is at the treatment site removing bacteria what you have left is nutrients and the same as with fertiliser it can help to grow so if you saw would you consider using?*
Interviewee: *I would consider using because of individual differences I would use because I have witnessed before so maybe the fish has taken some of the faeces so you take out the intestines so it's ok for me. when the produce is made like maize you have used cowdung to grow but it doesn't have inside but when you have fish it does so the same.*
(Household interviewee, 36-50, male, central area)

The quote from the Fanti interviewee shows how much different models can vary even across small distances and that perhaps waste-reared tilapia would be a system applicable in coastal regions. Overall it received very poor feedback in Sunyani that suggests it is one of the solutions less suited to the local context for generating value from sewage treatment.

4.3.2.4 Fertiliser

From the two farming villages interviewed there was varying use of fertiliser for agriculture in the areas with people using either no fertiliser, animal droppings, or the two branded fertilisers NPK or 15-15-15. The main issue of choice between the options was costs with people often using animal droppings from friends as they could not afford fertiliser:

Me: *Do you use fertiliser?*
Interviewee: *No. People have explained the purpose but I don't have the money to afford the fertiliser.*
Me: *So are you aware of any fertilisers available?*
Interviewee: *My desire is to buy fertiliser but I don't have the money.*
(Farmer interviewee, 36-50, male)

Me: *Do you use fertiliser?*
Interviewee: *yes I use NPK but when I get not much as it is expensive.*
(Farmer interviewee, male)

Me: *How much fertiliser do you use in a season?*
Interviewee: *I don't use*
Me: *Why is that?*

Interviewee: *My problem is that there is no money to buy the fertiliser so sometimes I go to the poultry farming and ask for droppings to apply to crops.*
(Farmer interviewee, male)

The idea of using excreta as a fertiliser was one well known in both villages when asked about the possibility of using in interviews, with people often having heard about it through word of mouth or having used animal droppings to aid their crop growth. This was particularly prevalent in Jato Nkwanta where people were often migrants from Northern regions where use of faeces for crop growth is more widespread (Cofie, et al., 2004):

Me: *If you saw a fertiliser from waste would you consider? Why?*
Interviewee: *I was told it helps to grow the crops so I would buy.*
(Farmer interviewee, female)

Me: *So what we're looking at is producing fertiliser from waste treatment so if you saw a bag in the shop would you consider buying?*
Interviewee: *I'm trying to link sometimes in the olden days they used cow dungs and chick droppings we use so if I saw anything like that it wouldn't be different.*
(Farmer interviewee, male)

Me: *Would you consider using?*
Interviewee: *that's an old technology so farmers have used cow dung before and it made crops grow faster so if I saw something of that sort. They are old systems and then there are new systems so at first cow dungs so may be if new came.*
(Farmer interviewee, 50+, male)

Me: *So the purpose is looking at producing from toilets*
Interviewee: *I know I already have 3.5 acres where I apply faeces from poultry so I know it is good. I know when it rains the fertiliser is still working whereas chemicals dissolve this mixes with soil so would be very very helpful.*
(Farmer interviewee, 50+, male)

A few farmers in Jato Nkwanta also cited issues with the landowner as to why they did not use fertiliser:

Me: *would you consider using?*
Interviewee: *the problem is still that the owner needs to share the costs for the*

fertiliser. If I buy my own I will be cheated.
(Farmer interviewee, 36-50, male)

Like with biogas, people often had two different approaches to how they would decide to use a new fertiliser product, between those that would use it based on recommendations and those that would try it and contrast with existing products:

Me: *Would you consider buying fertiliser generated from waste if you saw it?*
Interviewee: *It all depends on the person selling it to me. The person is able to explain it well, how it functions, how it works then I would purchase one and see if it works well.*
(Farmer interviewee, male)

Me: *So if you saw a new product available what would you want to know?*
Interviewee: *because this one was introduced to me if someone showed me I would try it and see if it can grow me more crops so I can get more money.*
(Farmer interviewee, 50+, male)

Me: *If when you go to the market someday if you saw different fertiliser available what would you want to know about it?*
Interviewee: *it depends on how the shop owner explains it to me. After explanation I would buy old one and new one and test which will benefit.*
(Farmer interviewee, 50+, male)

Me: *If you saw new fertiliser what would you want to know?*
Interviewee: *I'd buy because I tried 15-15-15 and NPK before so I'd also try and see whether it works well. I would buy it, and use it and if it works well I would use it more.*
(Farmer interviewee, male)

Using treated faecal sludge as an agricultural product clearly has a potential market in farming areas around Sunyani, though it would require a lot of marketing and demonstration to show the potential of the products.

4.3.3 Technical Viability of Different Resources

4.3.3.1 Biogas

As a technical solution to faecal sludge treatment biogas is quite a technologically complex system and would require skilled operation and maintenance (Strande, et al., 2014). The main consideration for the suitability of biogas production as a fuel

for cooking is the proximity from the production to the point of use. The greater the distances that the gas needs to be distributed over for use, the more technological systems are required for compression and storage (Kapdi, et al., 2005). From informal conversations with a biogas producer in Accra the biogas systems are more effective if producing only select quality of faecal sludge, and they specifically chose public toilets for treatment rather than providing a city-wide solution. Direct use for electricity production would negate the need for compression and distribution systems but would need a supply deal with the government as they are the only viable customer for electricity. Biogas systems may also need further treatment of the remaining sludge, which could possibly be used for agriculture (Diener, et al., 2014; Tilley, et al., 2014).

4.3.3.2 Aquaculture

One of the main concerns with an aquaculture-based treatment model would be the hygiene of the workers and labourers on the job. With it being difficult to avoid contact with wastewater in harvesting duckweed or tilapia in ponds they are at high risk of parasitic infections (Iqbal, 1999). In Bangladesh workers rarely used protective equipment such as waders, wellingtons or gloves that would aid protection due to their movement restriction and the warm climate (Iqbal, 1999). From observations of the lack of protecting equipment with many truck operators it is likely that treatment models that risk wastewater contact would be exposed to the same risks.

The other technical consideration for aquaculture-based models is the level of technical sophistication needed to raise tilapia in WSP systems. The study based in Kumasi (Waste Enterprisers, 2012) did not conclusively establish whether there was a need for supplementary feed to the nutrients in the pond or whether aeration may be needed to sustain sufficient oxygen levels. Any initiative in Sunyani would likely need a research stage before a potential business model could be fully demonstrated.

4.3.3.3 Agriculture

One of the main technical considerations for producing and distributing compost or fertiliser generated from waste treatment is the density of the product. Depending on the level of processing from raw faecal sludge, the material can still have a high density, which makes distributing it expensive, and challenging in the same way that

transporting raw faecal sludge is often a constraint leading to decline of transport infrastructure (Chowdhry & Kone, 2012).

4.3.4 Future Developments in Sunyani Sanitation

This section looks at how the sanitation chain across Sunyani could change in future years and the effects this may have on any potential technical system designed for faecal sludge treatment in the city.

4.3.4.1 Increase in Private Household Facilities

The SDGs have moved on from the MDGs focus on private facilities to aiming for 'safely managed sanitation services' for all by 2030 (UN, 2016). The government sanitation plan places main emphasis on improving management of public toilets and collection services (MLGRD, 2010). This indicates that public toilets will likely remain a prominent facility for the urban poor in Sunyani for the coming years. Faecal sludge from public toilets are better for biogas production than private toilets as their low retention time means there has been less stabilisation and more gas can be produced from anaerobic digestion process (Strande, et al., 2014). If biogas was to constitute part or whole of a city-wide faecal sludge treatment plan then there would need to be an assessment of the baseline quality and quantity of faecal sludge that can provide the input sludge, but also how it could change in the future years if people adopt more public or private toilets.

4.3.4.2 Population Increase

The population of Sunyani Municipal area increased from 61,992 to 123,224 between 2000 and 2010 (GSS, 2005; GSS, 2012), representing a growth rate of around 7% per annum. This represents a significant engineering challenge to any infrastructure provision across the whole FSM chain. At the household facility stage of sanitation, the increasing populations are likely to reduce the available space for private facilities in households, as was seen with compound sanitation in other areas of Ghana where rooms were converted for rental (Mazeau, et al., 2014). The increasing population could also lead to more densely built areas that place large constraints on the emptying services (Murungi & van Dijk, 2014). Finally, there may be a limit to the design capacity of the existing WSP systems that would not effectively treat the faecal sludge of the whole city even if properly managed.

The population increase of the municipality could also lead to the urban/peri-urban frontier expanding more, which may leave the farming areas that would be

customers for agriculture-based treatment models being pushed further away from the city.

4.3.4.3 New Toilet Innovations

There are a couple of different businesses starting to provide innovative and different toilet designs in Kumasi and Accra, which if spread down to Sunyani may change the technical context for any treatment system. Firstly, in Kumasi there is the clean team model (Hystra, 2014), with mobile toilets and a regular collection system. If this model was to spread to Sunyani, then there would be a more consistent engineered product than the current sludge that can vary from 3 days to 20 years old depending on whether it is a public toilet or the size of the private latrine. The fact that mobile toilets are often emptied between once and twice a week means the excreta would also be more suitable to biogas digestion due to its regular emptying times (Strande, et al., 2014). There is also a business in Accra that builds on-site treatment systems that discharge treated effluent directly into stormwater channels (Hystra, 2014). If a business such as this was to develop in Sunyani it may alleviate the demand of increasing population on the existing systems, though it is not clear at this stage how effective the systems are at treating waste. It is not clear either how long it would take for these systems to scale up in Kumasi or Accra before they even start to disseminate into the Sunyani market.

4.4 How can We Understand the Market for Sanitation Providers?

4.4.1 Business Environment

4.4.1.1 Economics of Sanitation in Sunyani

To understand and assess the impact of any changes to treatment models in Sunyani it is important to know the existing market environment for providers across the faecal sludge chain. This section presents the economics of public toilet operation, vacuum truck collection and the existing treatment point in Sunyani.

	Revenue/Cost in Ghanaian Cedis										
Item	1	2	3	4	5	6	7	8	9	10	Average
Income from Users		3308	450	3900	400	2700	2700	2700	3600	2700	2495.3
Emptying Costs	400	1560	260	440		325	1120			325	632.9
Attendant Pay					270	90	168			200	182.0
Cleaner Pay					152	40	240			100	133.0
Assembly Contribution					100		60				80.0
Chemical Cost		277			200						238.3
Sheets Cost		50				600					325.0

Table 4-5: Table of Monthly Costs and Revenues from Public Toilets in Sunyani

Table 4-5 shows the economic environment for people running public toilets, with the blank sections where interviewees either did not know or did not want to divulge the cost or revenue. Whilst most public toilets make a revenue of around GHC3000 a month, or GHC36,000 a year, a couple interviewed gave very low estimates for usage of their facilities. These were mainly older, poorly maintained facilities that were in less central areas with less of a footfall and passing public. Public Toilet 3 and 5 seem to be making large losses when the other costs would be considered, so there is a question either of the reliability of the economic data given or how long the facilities are going to remain in this management structure. The public toilets with largest incomes were usually based around dense areas and provided a more hygienic facility than the others, though it's not clear whether the density of geographical customers funds better maintenance or better maintenance draws more customers. In dense areas around markets it is perhaps more likely that the guaranteed large amounts of people passing through allows for sufficient revenue for maintenance. What is clear is that running a public toilet in Sunyani, particularly in a market area or dense urban area is a quite lucrative business opportunity. This was clear when talking to a local businessman whose friend ran a public toilet and was *'building another in case the government changes at next election'.* At times, some of the data is quite inconsistent, with the pay at toilet 6 and 10 having large variations between the answer by the operator and the owner. This was the only time where I was able to interview the owner as well as the operator in separate situations so there could be these seem discrepancies in all the other economic data given.

	Revenue/Cost in Ghanaian Cedis				
Item	1	2	3	4	Average
Income Dry Season	4200		3857	31500	13185.6
Income Wet Season	7000				14118.9
Repairs	500	100		4000	1533.3
Staff	2,000	1500	1300	15000	4950.0
Fuel Dry Season	1800		1483	10500	4594.4
Fuel Wet Season	3000				4994.4
Dumping Fees Dry Season	600		593	4200	1797.8
Dumping Fees Wet Season	1000				1931.1

Table 4-6: Table of Costs and Revenues from Vacuum Truck Operators in Sunyani

The data given by trucking companies, shown in

Table 4-6, seems slightly less reliable. One of the issues is that with less competing providers it is harder to spot answers that seem anomalous due to the limited

number of providers in the context. The largest uncertainty in the data is from trucking company four, as the interviewee often seemed unsure of his answers. With providers 1 and 2 it was possible to corroborate the answers from two different interviewees giving a better sense of the reality for the providers, though the second providers were unable to share much information. Arranging the interview with provider 4 took most of the duration of the research and then resulted in a long wait for the meeting on arrival which brings into question how willing and engaged they were in being interviewed. The largest uncertainty for the research objectives from this data is trying to understand how many trips are made to the disposal site and how much faecal sludge is disposed there.

Assessing the economics of the disposal site management is difficult as the main source of income is based on how many trips are made to the site, which as discussed from

Table 4-6 is hard to be certain about. As the company that is largest is also the source of the biggest uncertainty it can only be estimated without conducting observation at the disposal site, with yearly trips ranging from 2,200 to 5,000. To make better estimates of any treatment model this data needs to be triangulated with better certainty, both to understand the economic income from tipping fees and the design criteria. This is an issue that was found in Ouagadougo when poor estimates of the faecal sludge flows to a disposal site led to designing at double the capacity needed which results in huge capital costs (Strande, et al., 2014), and possibly a reduced income from tipping fees versus the expected model.

4.4.1.2 Economics of Cost Recovery

The government's national sanitation plan aimed to pursue full cost recovery in both solid and liquid waste management (MLGRD, 2010). Currently the tariff structure for managing the treatment site in Sunyani is not sufficient to achieve cost recovery according to different stakeholders, as shown by the following quote from a stakeholder:

Interviewee: *In its current state it is not of interest to businesses as the fees for collection combined with the dumping fees are not economical to fund treatment of waste.*
(Stakeholder interviewee, academic in waste management in Ghana)

This opinion was also expressed when visiting the waste treatment plants in Kumasi, with a need to increase the dumping tariff to achieve cost recovery cited. The research was unable to observe rates of dumping at the disposal site so based on interview responses from companies has calculated break-even tariffs for the WSP if dumping fees are to be the only income stream. Staff Assumptions:

- Staff requirements:
    - Without Aquaculture: 1 manager, 6 labourers, 2 assistant foremen (Arthur, 1983)
    - With aquaculture: 1 manager, 8 labourers, 2 assistant foremen
- Staff Costs
    - Manager: 1250*inflation from 2010= 2600 (Waste Enterprisers, 2012)
    - Labourers: 260 (Waste Enterprisers, 2012), 350 (stakeholder interviews)

Item	Min Unit cost	Max Unit Cost	Source
Desludging	10000	20,000	Interviews and (Waste Enterprisers, 2012)
Groundskeeping equipment	200	200	(Waste Enterprisers, 2012)
Aquaculture Equipment	2000	2000	(Waste Enterprisers, 2012)
Total	12200	22,200	

Table 4-7: Capital costs for aquaculture

Operating Costs	Min Unit cost	Max Unit Cost	Unit/yr	Min Year Cost	Max Year Cost	Source
Labourers	260	350	96	24960	33600	Interviews and (Waste Enterprisers, 2012)
Manager	2600	2600	12	31200	31200	(Waste Enterprisers, 2012)
Desludging	10000	20000	1	10000	20000	Interviews and (Waste Enterprisers, 2012)
Total				66160	84800	

Table 4-8: Operating costs for aquaculture

Cost Recovery Tariff					
	Losses	Low Trips/Year	High Trips/Year	High Break-Even Tariff	Low Break-Even Tariff
Minimum Cost	65,760	2,176	5,000	30.22	13.15
Maximum Cost	84,400	2,176	5,000	38.79	16.88

Table 4-9: WSP cost recovery tariff

If resource recovery is not part of the treatment approach in Sunyani, then cost recovery would have to be achieved from dumping tariff revenues. Based on the estimated trips from providers of 2176 trips a year, a dumping tariff of between 30 and GHC40 would be sufficient to cover costs. If the higher interview estimates of 5,000 trips per year are true then the tariffs would only need to be GHC13-17 to fund cost recovery which would suggest a management failure rather than insufficient funding. It seems more likely that 5,000 trips per year is an over-estimate and tariffs are currently too low to fund cost recovery as this complies with stakeholder

interviewees from different cities across Ghana. For calculations around resource recovery the lower estimate of 2,176 trips per year will be used.

Before pursuing cost recovery from treatment an analysis of how this would affect tariffs at public toilets and private latrines would be needed and then whether the price increase being passed on may increase either illegal dumping or open defecation. If the GHC30-40 tariff required for full cost recovery was passed directly on to the toilet owner the GHC10-20 increase per trip would constitute a 6-12% increase on the GHC150 fees paid to vacuum trucks currently. For public toilets, if the cost of the GHC20 dumping fee was passed on to the users it would constitute an increase per use of between GHC0.01 and GHC0.03, which if passed on to users could only be done by an increase of GHC0.05 cedis which is a 20-30% increase in the cost of sanitation for the use of public toilets that would affect the urban poor disproportionately. This shows the importance of looking at different ways of funding faecal sludge treatment so as to avoid increasing the price of sanitation for the urban poor which could lead to open defecation or unhygienic practices affecting public health.

Aquaculture Revenue						
	Min Price/Unit	Max Price/Unit	Unit/yr	Min Year Revenue	Max Year Revenue	Source
Tilapia	3.7	5.7	1479-7066	5472.3	40276.2	Interviews, Iqbal and (Waste Enterprisers, 2012)
Duckweed	4	4	1500	6000	6000	Interviews and Iqbal

Table 4-10: Revenues from Aquaculture Resource Recovery in Sunyani

In terms of retrofitting systems to the waste stabilisation ponds to generate resources, if growth of tilapia in the final ponds was introduced and all fish were grown at stocking densities between 2 and 6/m2 the break-even tariff to cover maintenance would still be between GHC15 and GHC40 assuming that all fish can be sold. Whilst there are some large uncertainties in the economic data it seems clear that a tariff increase for dumping would be likely in Sunyani if cost recovery is pursued. In its current state retrofitting tilapia or duckweed production would not have enough impact to enforce proper maintenance.

The potential for aquaculture-based resource recovery to decrease tariffs is still positive, though the limited effect combined with the social reluctance to adopt both resources means it is unlikely to fund treatment.

4.4.1.3 Economics of Resource Recovery Models

4.4.1.3.1 Biogas

Due to the limited funding and time for fieldwork, obtaining technical and financial data about the specific application of biogas in Sunyani, Ghana. Instead different sources of literature are used to estimate costs and revenues for potential economic forecasts. Murray et al (2011) assessed the economic potential of biogas for a population of 100,000 people which is not dissimilar to the population of Sunyani. This paper was also investigating biogas potential in a Ghanaian context with a local manufacturer. Academic interviewees and public toilet operators had also been investigating the cost and possibility of building and operating biogas plants so had estimates on building costs and operating potential. From interviews with a company producing biogas in Ghana for electricity, the faecal sludge from 15 public toilets selected for their sludge quality and organic waste from markets could power a 100kW generator. Over a year at a purchase price of GHC0.32/kWh (PURC, 2011) this would generate revenues of GHC272,000 (USD68,000). Using faecal sludge volumes flows from the research and quality specifications of sludge in Accra (Kone & Strauss, 2004) shown in Table 4-11 the biogas equation method from Ddiba (2016) in **Error! Reference source not found.** using a BMP value of 304Nm^3 C H_4/kg VS (Vögeli, et al., 2014).

Parameters	Accra Public Toilet Sludge	Accra Septage
TS (mg/L)	52,500	12,000
TVS (% of TS)	68	59
COD	49,000	7,800
BOD_5	76,000	840

Table 4-11: Parameters of waste in Accra (Kone & Strauss, 2004)

$$B_v = WS_v \times 1000 \times \frac{TS_v}{10^9} \times \frac{VS_m}{100} \times BMP \times \frac{100}{60} \quad (1)$$

$$B_v = WS_m \times \frac{TS_m}{100} \times \frac{VS_m}{100} \times BMP \times \frac{100}{60} \quad (2)$$

Where;

WS_v = amount of waste stream (faecal sludge) in m^3/day,

WS_m = amount of waste stream (sewage sludge or organic MSW) in tonnes/day,

TS_v= amount of total solids in the waste stream in mg/L,

TS_m= amount of total solids in the waste stream as a percentage of the total mass,

VS_m = amount of volatile solids in the waste stream, as a percentage of total solids,

BMP = biomethane potential of the waste stream in Nm^3 CH_4/tonne VS_{added}.

Figure 4-7: Equations for Biogas Estimation (Ddiba, 2016)

Gtz provide a method of estimating costs for biogas plants using basic material costs, which is applied both for a per-capita calculation and for the estimated faecal sludge volumes from the city. The components of cost from GtZ are: 6.5 sacks of cement(per m^3/capacity), 5 days work for a mason(per m^3/capacity), 100m gas pipes (1/2”), two ball valves (1/2”), gas appliances feasible for the digester size (Kossmann, et al., 1999).

Cost/Income	Value ($, $/year)	Justification/Source
Public Toilets Only		
Capital Cost	459,800	(Murray, Cofie and Drechsel, 2011)- electricity
	432,520	(Murray, Cofie and Drechsel, 2011)- direct gas
	412,500	Public Toilet Owner
	64,500	(Kossmann et al 1999) and Interviewees
	257,482	(Kossmann et al 1999) and Sludge Generation per Capita
Revenue- Electricity	33,440	(Murray,Cofie and Drechsel, 2011)
	149,600	Accra Biogas Business
	68,750	(Ddiba, 2016) and interviewees
Revenue- Gas	84,920	(Murray,Cofie and Drechsel, 2011)
Operating Costs- Electricity	20,860	(Murray,Cofie and Drechsel, 2011)
Operating Costs- Gas	18,920	(Murray,Cofie and Drechsel, 2011)
All FS in Sunyani		
Capital Cost	1,254,000	(Murray, Cofie and Drechsel, 2011)- electricity
	1,179,600	(Murray, Cofie and Drechsel, 2011)- direct gas
	220,400	(Kossmann et al 1999) and Interviewees
	406,000	(Kossmann et al 1999) and Sludge Generation per Capita
Revenue- Electricity	91,200	(Murray,Cofie and Drechsel, 2011)
	101,800	(Ddiba, 2016) and interviewees
Revenue- Gas	193,000	(Murray,Cofie and Drechsel, 2011)
Operating Costs- Electricity	56,400	(Murray,Cofie and Drechsel, 2011)
Operating Costs- Gas	51,600	(Murray,Cofie and Drechsel, 2011)

Table 4-12: Estimated economic values for biogas in Sunyani

Using these estimates different economic projects based on upper and lower bounds of the estimates are shown for generating electricity from biogas due to its easier use and not needing to sell to households or process and store gas. Figure 4-8 to Figure 4-10 show the economic potential for biogas to electricity from the public toilet waste in Sunyani. The most viable estimates in terms of profitability is based upon the current performance of the biogas production site in Accra which is positive as the actual performance of biogas plants there would be profitable for ranges of costs at an interest rate of 22% per year if the waste in Sunyani is similar quality and viability.

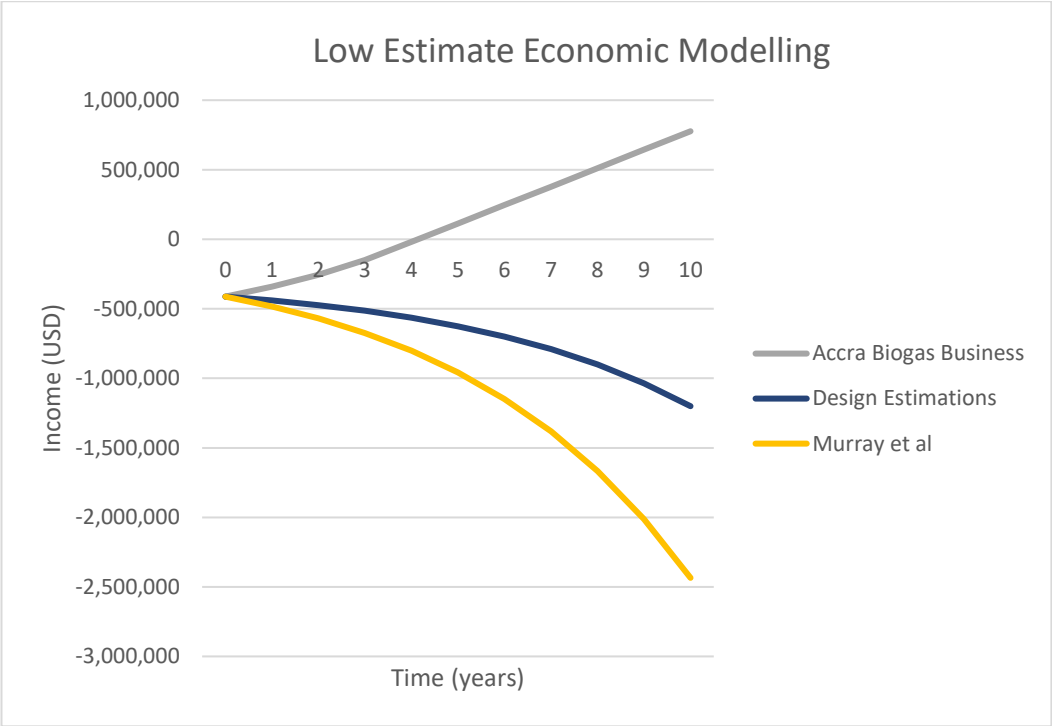

Figure 4-8:Low Estimate Biogas Economic Potential

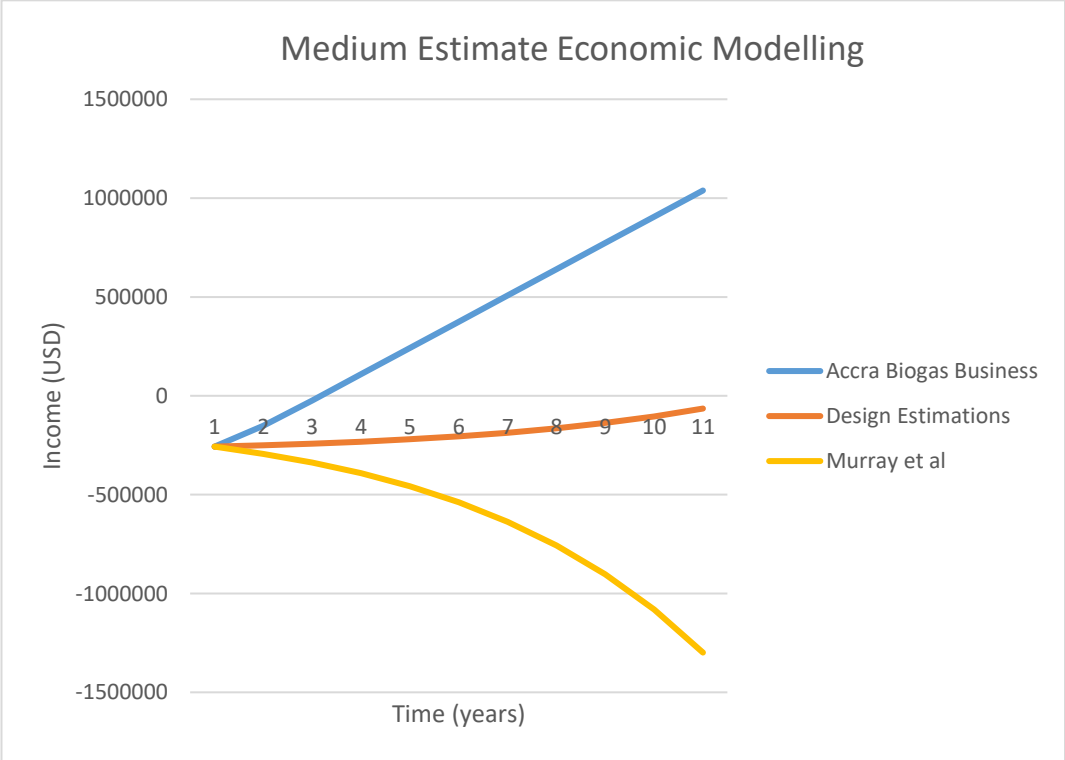

Figure 4-9:Medium Estimate Biogas Economic Potential

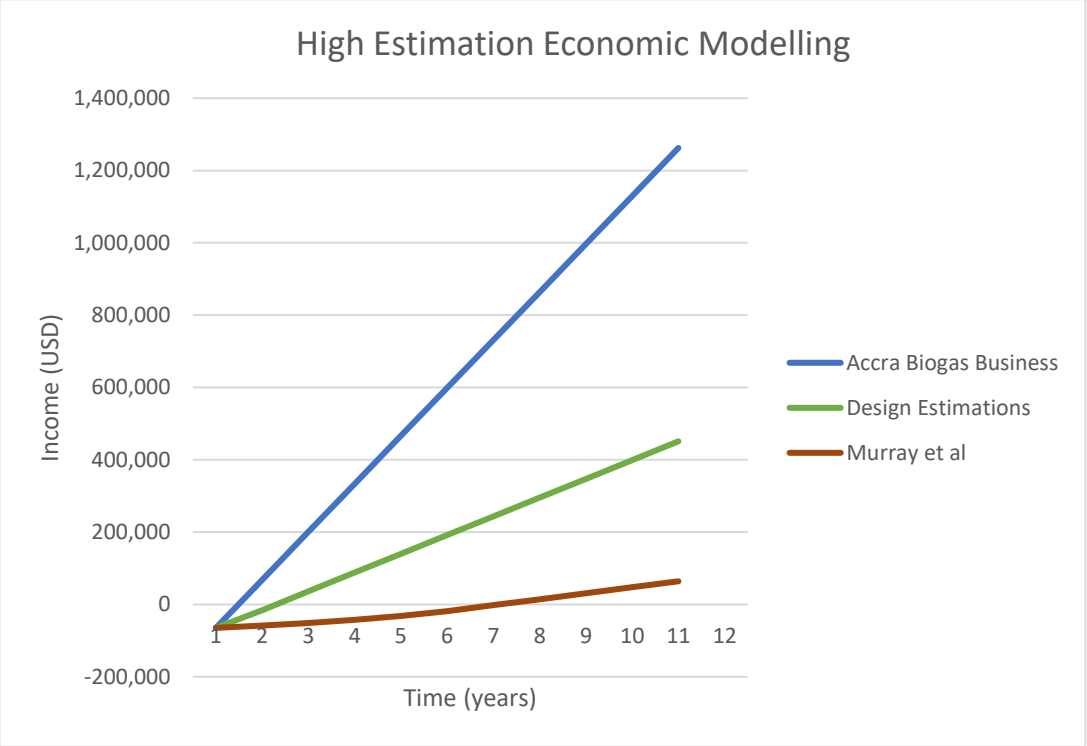

Figure 4-10: HIgh Estimate Biogas Economic Potential

There is clearly a potential to generate significant revenues and profit from operating biogas systems based on the literature and interview sources of data, though it remains dependent on accessing the initial capital and the quality and quantity of sludge collected in Sunyani. Depending on the source of finance and the terms on which it can be secured this could have a large effect on the long term economic sustainability of biogas production. The main uncertainty for economic forecasts in Sunyani are the costs of set up and the suitability of the different public toilets and organic waste in the city for biogas yield, but the implementation of biogas in other cities suggests that it could be profitable. The fact that the more profitable option is to only treat waste from public toilets also raises the question of what is then done with the waste from private toilets that could be increasingly prevalent. If run by the private sector this could be another example of 'cherry-picking' where only the viable waste is treated, and the government is then left with the unattractive, unprofitable aspects of waste treatment.

4.4.1.3.2 Duckweed

Duckweed growth on the final ponds of treatment systems can yield around 20 t/h.yr (Iqbal, 1999). From satellite images, the three tertiary ponds have a total area of 736m2 or 0.0736hectare, which could grow 1.47 tonnes a year. Currently fish

farmers come from different surrounding towns and villages to buy prepared feed. If the duckweed is dried and pelleted it could also be sold prepared at local markets. Selling fresh would require regular distribution as fresh duckweed only lasts 3 days if kept cool and damp (Iqbal, 1999).

Ranaan is the only source of complete fish feed sold in Sunyani, at a price of GHC80 for a 20kg bag. Duckweed would need to be sold in combination with a high carbohydrate source such as wheatbran to provide the full diet for tilapia. At GHC4 per kg a yearly revenue of GHC6,000 could be generated. In terms of capital cost the main expense is in desilting and restoring the treatment ponds which was estimated at a cost of GHC20,000 by the manager of the site who was applying for funds. Other than that, staff would be required for pond maintenance and collecting the duckweed as it is highly labour intensive compared to standard WSP operation (Iqbal, 1999). There would also be fuel costs associated with the regular transport of the product if sold fresh.

As a retrofitted option to the existing WSP in Sunyani the growth of duckweed has the potential to perhaps be a low investment, low profit business model more suited to individual entrepreneurs maintaining the ponds. The main constraint would seem to be either setting up a pelleting system, which would require a larger investment, or an efficient distribution system to ensure regular sales. From informal conversations with academics in aquaculture there are other plants that could have more potential as a business model in waste-based aquaculture. These models often exist on a larger scale in Asia where growth of morning glory and water mimosa for human consumption make large commercial businesses (PAPUSSA, 2004). The systems here are based on growing on small plots around a sewage channel where they are discharged so to be replicated in Ghana would be dependent on a large amount of land acquisition and diverting of existing faecal sludge disposal systems.

4.4.1.3.3 Tilapia

In a waste based rearing system it is possible to rear the fish tilapia at a yield of 6.7t/h.yr (Iqbal, 1999). This provides a yield of 493kg of fish per year from the tertiary ponds. Another business tried waste-based catfish rearing at densities of 4.72 and 2/m^2 (private communication). Using the lower estimate of 2/m^2 and a growth period of 6 months would yield 2944 fish/year, or 981.33kg/year assuming a fish size of 0.33kg which was the standard sale size at fish farms in Sunyani.

At a sales price of around GHC12 per kg when the fish weigh 0.33 kg, annual tilapia sales could generate GHC5,916-11,775. The capital costs would be the same as the duckweed with the main requirement being to restore the pond and maintain operation with staff. There are also capital costs associated with buying the initial stocking fish. Operation would again require staff, and possibly supplementary feed.

Tilapia, similarly to duckweed, is a treatment model that would be a low capital and low profit approach to faecal sludge treatment in Sunyani that could be operated by single entrepreneurs as Tenkorang et al (2012) propose. The main constraint to the economic model would be the rejection and lack of demand for the idea of the product at first which suggests that for it to work would take a lot of campaigning to convince people of the safety of the idea of eating waste-reared tilapia.

4.4.1.3.4 Fertiliser

Dried faecal sludge could be sold directly to farmers as a soil amendment at markets in Sunyani. Assuming a solids content of 35g/l (Diener, et al., 2014) and 216m3 a year of faecal sludge from public toilets based on emptying frequency of once a fortnight that was given by public toilet owners, there is a total solids content of 7.56t/yr at a public toilet if sold directly there or 250 tonnes per year from all 33 toilets.

As there is little market for faecal sludge as an agricultural product, it is hard to estimate the sale price that could be generated. With the use of poultry droppings it was often on a charitable basis between farmers without cash exchange so sales of USD4/ton, or 15.2 Cedi/ton, are assumed based on other African cities (Diener, et al., 2014). All the sludge from 1 public toilet could be sold at GHC114 per year, or GHC3800 for all public toilets. As biogas production is expected to leave only around 17% of the total solids to be sold as fertiliser (Diener, et al., 2014), this equates to potential supplementary revenues of GHC20 per year or GHC646 per year for 1 and all public toilets respectively.

4.4.1.4 Technical Viability of Models

The literature review stage identified resource models that could potentially be applied in Sunyani as a faecal sludge treatment system but the understanding of the local technical context was limited. This section looks in more detail at the difficulties of each treatment model.

4.4.1.4.1 Biogas

The main issues with biogas production and distribution in Sunyani would be those cited in the literature review of compression and distribution if used as fuel for cooking. These costs were often not considered in the literature sources for business models which may make it an even higher initial investment and increase operation and maintenance requirements. Another issue if the biogas was to be produced centrally at the existing disposal site would be that of distribution. If it was done by road with trucks going to filling points then the issue of the poor road surface would become a double constraint limiting traffic disposing faecal sludge at the site and trucks distributing biogas after production. Direct production of electricity would negate these issues whilst still providing a needed supply of electricity.

4.4.1.4.2 Duckweed

The commercial viability of harvesting duckweed on the existing WSP systems in Sunyani is in fact limited from conversations with academics. The true potential of aquaculture models is shown in SE Asia where large wetlands are flooded and plants are harvested on the surfaces allowing families to profit from the nutrients in the wastewater and contribute to food security. This options technical viability, combined with the potential for water mimosa or morning glory for human consumption instead of duckweed, was not invested in the case study so the viability of finding large tracts of land that people could then use for farming is unclear in Sunyani. One issue with waste reared aquaculture in SE Asia cited was that of the farmers getting ill from contact when harvesting. This would have to be considered against the benefits of the public health aspect of improved faecal sludge treatment. From the economic analysis the waste stabilisation pond systems are too small for duckweed or plant harvesting to be economically feasible for maintaining costs so instead would require large tracts of land like in SE Asia.

4.4.1.4.3 Tilapia

Beyond the issues identified in the literature with maintaining proper levels of oxygen and supplementary feed for healthy tilapia, the main issue in Sunyani would be ensuring proper food preparation. The levels of coliform and bacteria in tilapia means that the fish would need to be well washed and cooked to be safe but from the quote from a local aquaculture academic fish preparation can often be unsanitary which would pose a health risk.:

Interviewee: *When people eat tilapia at home they will remove the gut but sometimes with businesses trying to rush and prepare may not happen* (Stakeholder interviewee, academic in aquaculture in Ghana, male)

From Figure 4-11 another health risk of tilapia rearing in WSP systems can be seen with that of skin damage if those working with the tilapia do not use protective equipment as is often seen in Sunyani.

Figure 4-11: Fish Farmers Harvesting Tilapia in Sunyani

4.4.1.5 Constraints to Sanitation Businesses

4.4.1.5.1 Access to Finance

One of the major motivations cited for private sector involvement in services is their ability to finance developments where governments cannot (Yeboah-Assiamah, 2015; Sohail & Cavill, 2009).

Different models of treatment in Sunyani would require varying sums of initial capital investment to either rehabilitate the existing treatment systems or to build a new system tailored to a different resource-based purpose. The following quotes from different stakeholders show the importance of being able to access finance for business in Ghana, and the difficulties that there are in getting finance.

The ponds for faecal sludge treatment are currently full and need desludging but there is no money available. So the waste just gets discharged untreated.
(Stakeholder interviewee, academic in waste management in Ghana)

Me: So if you were to make the investment in biogas how would you source the finance for it? Through a bank?
Interviewee: No through personal savings it's no good to use loans. The interest rate is too high so resorting to bank is difficult unless you are doing dodgy business to make money. If you want to have good profit you have to invest your own money.
(Public toilet owner, male)

From informal conversations with people the importance of capital was clear in Ghana, beyond sanitation and in all aspects of life. People often spoke of using money earned abroad to be able to invest in taxis to run or other business lines where the main competitive advantage seemed to lie in being able to get the start-up capital. This was also seen when liquid waste management was privatised in Accra and overseas Ghanaians used their capital to buy trucks and send them home to family members to run (Fobil, et al., 2008). This aspect needs large consideration when assessing the viability of different resource-based models for profitability, as while they may be profitable and provide a social good at the same time, if it requires a large investment than there may be more lucrative, reliable avenues that can be explored by businesses and people that have capital to invest in instead of faecal sludge treatment which has rarely been done by businesses (Schaub-Jones, 2012). The more the case for investment and capital provision from the public sector to start a model up the more the management model faces a risk of running into an un-competitive monopoly as the contracted company will have a competitive advantage as competitors would need to provide finance to be able to produce biogas instead.

4.4.1.5.2 Demand

The issue of low, or sporadic demand cited in literature when looking at sanitation as a business was at times an issue seemingly in Sunyani. The main result of this is that liquid waste management was often a small element of larger businesses in the area who could seemingly afford to cross-subsidise the business through fallow periods with more lucrative areas of services.

4.4.1.5.3 Scale

Similarly to the issue of demand, the issues of economies of scale in sanitation, particularly transport, were again solved by larger businesses that could cross-subsidise activities and provide economies of scale. This was seen with the two transport companies who were able to provide their own repair services on site which will increase profitability of services compared to potentially using other businesses or even having to travel to Kumasi as might be needed for a single truck business in sanitation.

4.4.1.5.4 Private Sector Engagement in Sanitation

On a similar note to the discussion of issues with the inability to access to finance and the fact that it may drive companies or people with sufficient finance to areas with a more reliable profit margin, the attractiveness of the faecal sludge treatment sector as a whole needs to be considered. The following quotes are from interviews with stakeholders from the two large service-providing companies in Sunyani:

Me: What are your hopes for the business in the future?
Interviewee: In the future, currently we are only doing septic tanks but now we want to expand to janitorial services and provide full facility management.
Me: So is that for institutions?
Interviewee: Yes for institutions like schools, estates but also private households that want cleaning. Waste management would be a small part of this service.
(Business interviewee, vacuum truck operating business, male)

Me: Are these the same problems for the liquid waste side as well
Interviewee: Errm. With liquid waste because we don't, that one is small and in a day an average four trips a day and we have times when we use only 1 truck. You get me……So for the liquids and as I said there are other contractors around so we don't focus so much on.
(Business interviewee, vacuum truck operating business, male)

From these quotes it was clear that the companies that are in sanitation services in Sunyani are envisioning different directions to take their company activity. This implies that any sanitation model based on resource recovery would have to not only show the potential to make a profit but to be demonstrably high potential if it is to persuade people and companies to divert their investment into other areas. If resource recovery is not a source of a large profit margin model, then the ability to

increase tariffs may be the only way to engage private sectors to enter the market but this could affect both the incentive for proper management and drive people to open defecation instead of public toilets.

4.4.1.6 Political Environment of Sanitation

This section looks at the politics surrounding the whole sanitation chain in Sunyani and across Ghana, particularly in the context of the environment for sanitation as a business to operate. The focus on private sector is mainly around larger companies as that is usually how the private sector involvement in city wide services has been structured. While it is likely there will be informal collectors in Sunyani too they were not found often, and people usually referred to larger companies when talking about sanitation providers.

4.4.1.6.1 Public Sector Service Provision

The failing of the public sector in service provision is often cited as the driver for private sector involvement in industries (Bayliss, 2003). The reputation of the public sector was poor in Sunyani and with stakeholders across Ghana. Even amongst local assemblymen and workers in municipality across the country there was a view that the private sector would improve services.

Interviewee: *We asked private companies to come in to reduce problems with transport so there are no problems……Often with the bureaucracy it makes it difficult here. They have to come here, make a request, pay, take the receipt and then wait for us to empty whereas Company 2 can empty straight out in one call. Even though we only charge 110 cedi and they charge 150 cedi.*
(Stakeholder interviewee, waste management department local government)

Me: *So what are your aspirations do you hope to build more?*
Interviewee: *Not so much at the moment. Initially when I submitted the plans I wanted to build 2, then later convert the older public toilets to WCs but the government changed and I struggled with the government who thought it was their property and wanted to take the toilets from me. So now I'm not interested, it would have been nice to convert to WCs but the way it turned discouraged me. My intention was not to make money when I started the purpose was because I grew up poor and having access to toilets was often a problem for me and now god has been kind to me so I want to give back to community as I'm born and raised in Sunyani. I do not regret doing it because people patronise the toilets. If you're talking about*

looking at treatment it's not easy otherwise the government would do it. They do not want to do so they ask for help from the private sector. I have had calls about building more but now I have no passion to do it.
(Public toilet owner, male)

4.4.1.6.2 Monopoly

In Sunyani, the toilets were sometimes run by people who were previously in a place of power in local governments, or district councils, so there is a question as to whether these contract tenders are 'competitive'. The contracting of public toilets could be argued to constitute a 'geographical monopoly' particularly in the areas where there is no space or money for private household sanitation. The complaints about services seemed to centre in Odumase, a poorer less densely populated area, while public toilets in dense central areas had better perceptions of service. The collection service has two companies and different public sector actors in competition that seems to have improved services and there were few complaints from interviewees in Sunyani. This was also seen in Accra where a huge influx of vacuum truck operators outperformed the municipal assembly (Fobil, et al., 2008).

In Sunyani any move to introduce private actors to faecal sludge treatment would likely involve the transfer of a public monopoly to a private monopoly as there is only one treatment plant, so there would be little scope for a business to 'disrupt' the market if management of the WSPs in Sunyani are contracted out. If resource recovery is not a significant driver of effective management then this places a large burden on the regulating capacity of local government to ensure that the management of the pond system is effective and that the contracting process gets the best option for the government.

4.4.1.6.3 Regulation

The scope of this study was too short to truly assess the presence and strength of regulation in Sunyani, the only information that can be drawn is from the widespread failure of faecal sludge treatment plants that suggests the absence of a strong regulatory body that can enforce environmental standards. Reasons given for the failure often varied though, with some citing the inability of waste departments to manage their own budgets meaning that costs of maintenance could not be recovered, whilst some suggested it was simply people failing to do their job. The possible absence of regulatory capacity needs to be considered when looking at

possible private management of faecal sludge treatment as to how operating contracts would be tendered and structured.

4.4.1.6.4 Electoral Uncertainty

One of the aspects that kept arising with sanitation as a business and its management in Sunyani was the relationship between the changing services and the electoral cycle.

Me: *So what are your aspirations do you hope to build more?*
Interviewee: *Not so much at the moment. Initially when I submitted the plans I wanted to build 2, then later convert the older public toilets to WCs but the government changed and I struggled with the government who thought it was their property and wanted to take the toilets from me. So now I'm not interested, it would have been nice to convert to WCs but the way it turned discouraged me. My intention was not to make money when I started the purpose was because I grew up poor and having access to toilets was often a problem for me and now god has been kind to me so I want to give back to community as I'm born and raised in Sunyani. I do not regret doing it because people patronise the toilets. If you're talking about looking at treatment it's not easy otherwise the government would do it. They do not want to do so they ask for help from the private sector. I have had calls about building more but now I have no passion to do it.*
(Public toilet owner, male)

Me: *How long have you been owner of the toilet?*
Interviewee: *2008 so around 7 years*
Me: *How did you come to operate?*
Interviewee: *Initially it was a community toilet run by the community watching over then they gave it to a committee then I was in part of the committee so then a time came when people have to apply for it so I wrote a letter to the unit area council.*
(Public toilet owner, male)

Me: *So when was the ponds constructed?*
Interviewee: *It was constructed around 2003-2004 If it's well maintained it should last forever. Then around 2008 the problems started.*
Me: *Is solid and liquid waste management an important issue for voters?*
Interviewee: *Not voters, communities of people. In Ghana we do not want to bring politics into it. It's important yes, before construction of ponds there was a lot of*

problems with handling.
(Stakeholder interviewee, waste management department local government)

These issues also arose in informal conversations where someone said their friend ran a public toilet and was building one in case they had the contract removed from them after the next election, which has now passed with a change of president. People often said that if the government was to change at the election then there would be a large change in the staff managing sanitation in Sunyani. This could potentially raise issues with continuity if a lot of knowledge is lost with each electoral cycle. The citations of dates often centred around electoral dates in terms of when infrastructure would start declining or when provision of services would change. There is also a possibility that there is an element of confirmation bias where people attribute failures to the party that they do not support.

It is difficult to retrospectively establish the link between failure in infrastructure, changes in contracts and electoral turnover but the perception alone is still important for the research. The doubt and uncertainty businesspeople feel around election time would raise the question as to whether companies or people would want to make large investments in infrastructure if their contract situation would change if the government did.

4.4.1.6.5 Budgeting

One of the key differences cited between private and public management models in Ghana is the ability in the private sector to maintain services when there are delays in government payment disbursals. This was cited by different stakeholders as a benefit of the private sector model of service provision:

We also have to get into arrangements with other bodies. Apart from that we have other programs and subsidiary companies so that we don't default…. Apart from that there is this issue of funding, as I said it's an arrangement with the assembly but the fund doesn't come as it should but you still have to make clean.
(Business interviewee, vacuum truck operating business, male)

Fuel is the other large problem as the funding from charging for emptying and dumping goes to the assembly so cannot be taken and takes time to get the money for fuel because of bureaucracy. Sometimes can be waiting for a whole week. If it had separate account could reduce problems.
(Stakeholder interviewee, waste management department local government)

Currently there are no fees charged for dumping solid waste and small fees for liquid waste which go to the assembly so when they need desludging or maintenance there are no funds available
(Stakeholder interviewee, academic in aquaculture in Ghana, male)

This inability of government departments to maintain services in periods of volatility or delays in funding is a key issue that has led to the increasing involvement of private sector actors who have other sources of income allowing them to maintain services in the intermediary periods waiting for payments from government. The current arrangement for management does not allow for a ring-fenced budget that can be used for maintenance, instead all fees go to local government. This is one of the key aspects that was highlighted both as a reason for the existing poor level of service from faecal sludge treatment and as a driver for opening faecal sludge treatment to private management. This ability to ring-fence operating budgets would also be key for any resource-based model to be initiated as a way of recovering value from the waste, as otherwise the profit incentive to harness value does not exist.

4.4.1.6.6 Inequalities of Services

One of the largest objections raised to privatising basic services is that it can actually exacerbate inequality with poorer people being costly and difficult to serve and instead investment and improved services accrue in wealthy areas (Sohail & Cavill, 2009; Budds & McGranahan, 2003; Carter & Danert, 2003; WaterAid, 2016). Bayliss and Fine (2008) suggested that:

'private sector presses to provide when and where it is profitable for it to do so (and to use the state to make it so) and, equally, does not embark upon, or abandons, provision where profitability fails'

This trend led to water services in Ghana being separated into lucrative urban water that was contracted to the private sector and rural water that then lost the benefit of 'cross-subsidisation'. This trend of 'cherry picking' could possibly be present in sanitation in Ghana, where often the private sector was often linked with better service when talking to stakeholders but there is also the possibility that they enter the market when there are public toilets that are easier to manage and have a larger customer range. For example in dense areas such as markets there is a large profit incentive for private management and the funds there that can be raised are

sufficient to maintain the infrastructure, whereas some of the toilet blocks in poorer, less populated areas like Odumase may still be run by the government or local political leaders rather than businesses but without the ability to cross-subsidise operations from the more profitable toilet blocks. This question was also raised looking at private management of water in Ghana where private sector had much lower unaccounted water, though whether they improved services or selected working profitable systems was not clear (Nyarko, et al., 2011). This issue could also apply in Ghana where private sector may only enter to faecal sludge treatment in larger cities where it is possible to achieve economy of scale or only take on working systems leaving more difficult systems to government, with businesses and different models being quite prominent in Kumasi and Accra. The other aspect to consider this is the contradiction to the narrative that private sector will simply provide a panacea to infrastructure problems such as in the national sanitation plan which expected the private sector to 'innovate in meeting the needs of the vulnerable especially the use of public facilities by physically challenged persons' (MLGRD, 2010).

4.5 Conclusion on Results

This case study investigated the potential for resource recovery as a business along the framework in Figure 3-1. The sanitation chain and providers were identified in Sunyani. A large proportion of the population relies on public toilets, whilst others also use private septic tanks or pit latrines. There are two private emptying companies as well as non-private actors who empty latrines and septic tanks and dispose at a series of broken down waste stabilisation ponds. Looking at the market for sanitation providers in Sunyani the economics of public toilet operation and private emptying services were analysed, as well as the potential for resource recovery as a business. Biogas and tilapia rearing were found to be potentially profitable businesses for sanitation providers, with biogas being a particularly viable business proposition from public toilet waste. In terms of the business environment the main challenges involved governmental relationships, particularly for public toilet operators, which may make any business approach risky depending on governmental changes. Access to finance was also a major constraint to sanitation providers raising the challenge of how resource recovery businesses would source start-up finance. In terms of how different sanitation systems serve people, there was some level of dissatisfaction with public toilets, especially in Odumase where they are believed to cause diseases to spread. For different resources that could be

produced from waste treatment tilapia and duckweed did not have a significant demand and tilapia was particularly disliked by interviewees. Compost for agriculture and biogas had better perceptions with households suggesting these two may be more suitable to produce. There was also a demand from government for electricity from biogas which demonstrates the suitability of electricity production as resource recovery.

Concluding overall on the results from Sunyani as to whether faecal sludge treatment can provide revenue for resource recovery, only biogas to electricity production seems a possibility as a viable option. Composting in Ghana has been shown to not achieve cost recovery and found a low value for sales, whilst duckweed is also of low value with quite difficult distribution requirements. Tilapia is a higher value product but entering it into the market would be highly difficult due to the level of reluctance amongst customers. Biogas however, if adopted to produce electricity, would only sell directly to the government and could connect to the grid at the point of disposal. The local government was most engaged in the possibility of producing biogas also, so it seems that it could be viable. From economic analysis it seems that it could be profitable dependent on the initial investment required and the quality and quantity of faecal sludge that can be collected from public toilets. Using biogas for waste from private toilet waste however is less economically viable due to the capacity required and the low anaerobic potential of sludge that has been stabilised. This raises the question as to whether the relationship between the private sector and the government in providing treatment would be similar to that of the public toilets in that the private sector enters the market to treat waste and provide electricity, which would still be an improvement, but does not contribute to the treatment of private waste still leaving an economic and environmental issue. If a government owned enterprise was able to operate the plant it may be viable to cross-subsidise other treatment methods for private toilet waste, but it would still require regulation and enforcement beyond self-interest of the operating business which was observed to be limited in Ghana. To further understand the different viabilities of different models studies should be conducted into the sludge quality of public and private toilets in Sunyani and any other organic waste streams that could be utilised, as well as looking at sources of finance available to different potential operators.

The case study of Sunyani is not considered suitable for ABM as the 'agency' that would effect biogas is mainly dependent on the economic viability of different models so the economic results available are the best current exploration of biogas potential. From what was observed in the operation there were limited issues with waste not being collected/disposed at the site as expected, and the success simply depends on a better centralised treatment approach. With better data around the relationships between the private sector and the government models could perhaps be made to understand different scenarios of management of facilities, but for now the major issue is understanding the potential quality and quantity of sludge to better understand the economic potential of biogas. From there a better model of the agents and operating approaches could be used before recommending expensive infrastructure changes.

4.6 Reflexivity

Having presented analysis of collected data from Sunyani with relation to sanitation provision, this section looks at the different aspects of how the researchers position in the case studies could have affected the research. It is impossible with such a wealth of qualitative data collection for my position and socio-economic background not to have an effect on people and how they interact with me and this section looks to investigate how my approach could have been perceived and how it affected the whole research process.

Understanding my position as a researcher and how my prejudices impose on the shape of the social research is an important step to take to ensure that the research is valid. As an engineer, it is a difficult step to take to reflect on how I am affecting results. My educational background before this PhD was grounded in positivism and objective observation, which is difficult to undo and change approach within a year of research. There is a balance to maintain between simply indulging myself and losing site of the actual research on one hand, and ignoring inherent biases to affect the interactions that underpin this research on the other (Furber, 2013).

The first difficulty that arises when acknowledging my inherent biases and subjective views is the notion that they are a single data point that can be stated simply. Instead, I have found that the opportunity to research technology and development has had a huge effect on how I think and perceive every aspect of the research. Over the years of research, my biases and interactions with the research have been fluid and ever changing, reacting and interacting with the research I conduct. When

looking at politically charged issues like sanitation, privatisation and the development/AID industry and their interactions it is hard for my political views not to influence how I write, interpret and analyse findings. Instead, the purpose of this section is to try to illustrate as much as possible the instances where my presence and changing biases have had an effect on interactions in my research and how I interpreted them.

4.6.1 Fixing the World

There is often a narrative that I feel I was attracted to in the development industry that it is the responsibility of the white man to go forth, civilise and fix the world's problems which is particularly encapsulated in Kipling's 'white man's burden' poem. The extent to which this idea prevails in modern development can be debated but it illustrates well my initial philosophy and motivation as I entered the development industry. Early trips to South Africa, Nepal and Malawi left me with a passion to use my engineering education to provide the basic services and infrastructure that I was fortunate enough to have back home. In my early period of undergraduate research, I found the disparities difficult to understand as the technologies needed were often simple, but over time my growing understanding of the wealth of social, economic and political constraints has tempered this belief that technology transfer would be able to balance the scale. That having been said, there were still many times in my fieldwork where this narrative of the white foreigner coming over to fix things existed both on my part and with the research participants.

The saviour syndrome that still follows me around starts at home before being in the field. Besides one or two academic colleagues, the majority of people who I discuss my research with receives comments along the lines of '*that's so worthwhile'* or *'you actually do something that makes a difference'*. Despite my protestations that '*I haven't actually done anything yet'* it's hard to deny that I spent most of the early research and fieldwork with an internal confidence that failed faecal sludge treatment systems are a design problem that I would be able to solve. I feel that this attitude spilled over into many interactions with research participants in Sunyani, Ghana, and was at times enforced by research participants.

Me: *What it is is its looking at biogas which where you take the waste from water closet you can mix with waste like banana peels and things then as it digests the gas will come at the top which will work similar to LPG. Have you ever heard or seen it before?*

Interviewee: *are you going to construct it?*
(Household interviewee, 20-35, female, central area)

Me: *So what are your aspirations would you like to build more toilets?*
Interviewee: *The area till down there (beyond maize farm) goes for 3km and it needs more toilet but right now I don't have the finance so if someone came I could build and start to manage.*
(Public toilet owner, male, Odumase)

Me: *Also a potential is looking at biogas has anyone ever come looking at producing biogas.*
Interviewee: *No but am interested so what would I do for you to build here.*
(Public toilet owner, male, Odumase)

Interviewee: *if the tree grows wrong or loses it strength then I would apply fertiliser*.
(Another interviewee was interrupting him and telling him that he should say he uses fertiliser more as it is an NGO so might be able to give stuff. Interpreter told me after)

The above interactions reflect a common trend that underpinned a lot of the research I conducted in Sunyani, where despite explaining the purpose of the research and my role within it the perception remained that I was looking to build a treatment plant myself. The final instance demonstrates most clearly the effect this has had on the interactions I had as the presence of other interviewees (it was hard to maintain privacy in certain cases) persuaded them to answer positively to my questions in order to benefit from free fertiliser. This trend is likely to be less explicitly present with other conversations based on the regularity with which I was asked whether I would build biogas plants or composting plants.

To understand this, it helps to base my presence in Sunyani in the context of other foreigners that visit Sunyani. Besides the workers at a local gold mine, who were regularly based at the 4-star hotel in the area, the white people throughout the city had one common thread of being there to help. This varied from missionaries, which is what strangers in the street often guessed was my purpose for being there, to doctors and volunteers working in orphanages. Around the midway point in my research after spending weeks explaining to people that I was researching options for sanitation that could be implemented by local businesses or governments and that I was not there to donate, an NGO worker arrived on the local campus to

present. Here they spent time demonstrating and describing the Urine Diverting Toilets that they were installing in the area. The presentation finished with the European NGO worker donating thousands of dollars to the University or a local charity (I was at the back and could not hear the full speech but only the applause and someone explaining the large donation to me.) He then left after a few meetings with academics and I did not see him about campus for the rest of my time there. During my time in the research there was also a foreign company working to implement a solid waste management facility and looking in to potentially treating faecal sludge long term, who I did not get the opportunity to meet. From the majority of white foreigners that visited Sunyani who were often looking to implement solutions I found it hard to shed my image of being another foreigner who was going to come and build something to improve people's lives short term. I have to accept that the narrative was true to an extent as well because at times my desire, if the research identified a sustainable business model, was to actually follow up and start a business in Sunyani. This will have had an effect on the narrative of trying to interact with people and understand their true acceptance/demand for resources.

Beyond the perception of people towards me and my research, there was also the more fluid notion of how I projected and perceived myself and my research during my time in Sunyani. As the research was quite exploratory and grounded in little prior knowledge and understanding of the local context and culture, my opinions and hopes were quite variable over time. It is an aspect that I find harder to find clear easy evidence of compared to the NGO/saviour perception and its effects on people's responses. I think the main thing that changed is how much hope or confidence I had in different technical solutions to be suitable to the context. The main presence of this that I can reflect upon is the way my approach to the potential for aquaculture changed over time. My initial research intention had been to look at aquaculture systems that could be retrofitted to WSPs due to the prevalence of broken down WSPs across Sub-Saharan Africa, but expanded to other resources to assess what options would truly suit the context of Sunyani. My initial research and literature review around fish rearing in WSPs gave me the impression that it was an approach that could change faecal sludge treatment in Sunyani and other cities. Over time in the social research though I found an outright rejection of the idea of eating tilapia reared in WSPs, as shown below:

Interviewee: *Now I would have a problem if I see it with my naked eye I wouldn't consume. Even now because most people don't eat dog it's because the dog they eat faeces that is the perception. So I don't think if I see it with my naked eye they are feeding the fish with the faeces when I'm taking it I will not feel happy.*
(Household interviewee, 18-35, male, central area)

Interviewee: *It is still very difficult for me to eat. From a Ghanaian perspective if you mention to them that it is produced from this they won't accept it. If you rear tilapia are you going to have any side effects*
Me: *….If you saw that available would you have concerns?*
can see their face reacting as the translation is explained
both start laughing alot.
Interviewees: *No we woudn't buy. If I see it that they produce it I will not buy.*
(Household interviewee, 18-35, male, central area)

Over time the negativity started to wear down my approach and at times it felt quite embarrassing to ask people about it knowing the sort of responses I would get. In some cases this may have led to researcher bias where particularly with an interviewee who was from the Fanti region I was quite taken aback and was almost following up to double check as I was so taken aback:

Interpeter explains concept of waste-reared tilapia

Interviewee: *I'm a fanti so where I come from they have sea and sometimes when we swim and when the waste is taken it is dropped in the sea so I know it happens. These fishes sometimes depend on the faeces and people go to the shore to defecate so if I saw I wouldn't be suprised if I saw it to buy.*
Me: *So the way it works for these is at the treatment site removing bacteria what you have left is nutrients and the same as with fertiliser it can help to grow so if you saw would you consider using?* Interviewee: *I would consider using because of individual differences I would use because I have witnessed before so maybe the fish has taken some of the faeces so you take out the intestines so it's ok for me. when the produce is madelike maize you have used cowdung to grow but it doesn't have inside but when you have fish it does so the same.*
(Household interviewee, 36-50, male, central area)

With the other aspects of the research there was less of a clear narrative of either total acceptance or rejection of resources. Though there is still a possibility that as I

spent time in Sunyani looking into the technical feasibility of different solutions or the expense, that my confidence or otherwise may have ran over into my interviewing style and influenced the way I projected different resources to research participants.

4.6.2 Inability to Conduct Different Methods

One experience in Sunyani due to the time available, difficulties of access and researcher relationships was that I was unable to carry out different research methods planned in section 3.3.4, instead the research used transect walks, interviews and observation. Group interviews were too difficult to arrange in the limited time available and instead it was a better use of time to be able to meet with households for individual interviews. The use of group interviews was also planned for pit emptiers and sanitation providers but these were less numerous than expected and harder to access even for individual interviews so group interviews were not possible. The only other methods not used were surveys and photography. Photography was not possible to arrange access and usage from households or pit emptiers so was not used, whilst surveys were not used in order to be able to focus on more detailed interviews. The key finding from this is the need to be flexible and adaptable to what methods work in practice and be open to the idea that certain methods will not be able to be carried out in future research.

4.6.3 Extractive Research

At times, my research verged into being what I had tried to design the whole process not to be, an extractive process where a foreigner drops in briefly to get his data and then disappears. Whilst this was a process I had been aware of from the start and had wanted to avoid, the logistical difficulties of trying to access different communities of farmers and fish farmers whilst only basing myself in the city centre made this narrative hard to avoid. The focus of the research would have needed to be more narrow with an increased timescale to be able to spend more time in communities. In the farming villages they could only be accessed by either taking shared taxis at 5:30 am, and then waiting, potentially for hours for a return taxi, or hiring a taxi which would cost more than what I was paying my research assistant daily. This need for early morning visits combined with the farmers need to get to work meant I only ever had short interactions that verged more towards closed surveys than the open discussions I had wanted. I think this also harmed the attempt of the research to be generate designs and data *with* communities rather than taking data from them.

This nature of extractive research was also present when interviewing fish farmers, as many locations were not known to my research assistant or any of his contacts. This meant that while we met the two fish farmers he knew in his own community the others we had to go with the fisheries department to meet. This meant that the interviews were often conducted whilst they were trying to work but also in the presence of workers from the fisheries department of local government, which will have affected the dynamic.

Whilst the fact that I was in the city meant I was more integrated to the areas I was researching in the centre there is still an element of integration I did not work hard enough to cultivate. This is a criticism that is often raised, by myself as well, around development work of the image of NGOs or development agencies that are separate to community and come flying in in white SUVs and then disappear. Whilst this was something I consciously made an effort to avoid, there were times where I think my introverted nature and personal circumstances contributed to me continuing this trend. In the haze of the research it can be hard to identify, as a combination of exhaustion, illness and being quite concerned about my family situation at home (where my father was suffering from terminal cancer) often led to me being withdrawn in nature. Another cause of this issue could have been the multiple communities that I needed to speak with, some of which were not logistically very easy to simply spend days in. I think the main point to take from this in the future would be to consider the balance between the time and stress from conventional structured methods on a 9-5 basis versus the benefits of simply spending time in the communities with a pen and paper in an effort to actually understand and integrate more in the area.

4.6.4 Participant Position

Another aspect of positionality that arose within the research was that of the position of the research participant. This was particularly prevalent when talking to stakeholders and sanitation providers, where depending on availability I could speak to different people within the organisation that would give different images of the challenges and realities of the companies that provide sanitation services in Sunyani. When talking to the two main companies that provided sanitation services I was given varying levels of access. With the first company my supervisor at the local university was a good friend of the head of Sunyani operations so I was given three different opportunities to visit the company. I was able to visit the disposal site with

truck operators, tour the public toilet facilities and interview both the head of all operations and the head of the faecal sludge side of the business. This gave me a good idea of how things operated within the company and was able to find dichotomies between different aspirations at different levels of the company:

Me: *Are these the same problems for the liquid waste side as well*
Interviewee (Head of Sunyani Operations): *Errm. With liquid waste because we don't, that one is small and in a day an average four trips a day and we have times when we use only 1 truck. You get me……So for the liquids and as I said there are other contractors around so we don't focus so much on.*

Me: *So do you have plans to expand or do anything more in liquid waste management?*
Interviewee (Head of Faecal Sludge Operations): *It's a capital intensive business so we're not looking to right now. At the moment our problem is with the disposal site where it needs an engineered solution so that it can be better. We're also looking at recycling. When it comes to the landfill site we also do it with the assembly with partnership arrangement and the assembly doesn't have the capacity to make it better currently so we'd be interested to hear your research or maybe discuss with you.*

With the other main provider of services, my research assistant and me spent many days trying to call the company to arrange an interview. A couple of times we spent hours waiting at the office to try and meet someone to no avail, and when I finally met with someone from the business it was a very quick, disjointed meeting as he was clearly busy and did not have a huge amount of time to talk to me. In certain aspects of the business he was unsure when giving answers as well such as when estimating the amount of disposal trips the company did to the treatment site, or how many collection points they went to a day.

The two contrasting experiences with interviewing sanitation providers in the city show both the importance of having access but also the variation between responses from different people within the same organisation. To fully understand the context of sanitation services from the point of view of the provider in the future it would be important to try and arrange as many interviews with people from different levels as possible.

A further consideration for community interviews is simply to consider whether they are a suitable research technique if certain areas have not had much experience of being interviewed. It may be simpler at times to spend longer periods with them and allow the methods to develop more into a normal sharing conversation than the extractive structured methods that seemed to develop at times.

4.6.5 Research Assistant Relationship

To focus solely on my own presence and position in the research would be to ignore and undermine the huge contribution in creating the research that was played by research collaborators from the local university. As covered in participant position my local supervisor was able to arrange access for me with many stakeholders and sanitation providers that might not have been open to spending their time talking to me if I had approached them myself. My local supervisor and research assistant were also valuable just in providing an understanding of the local culture throughout the day-to-day logistics of conducting research. Their knowledge of the local area was also valuable in being able to identify areas that were suitable for the dynamics I was looking for in my case study approach.

In stakeholder interviews and interviews with sanitation providers and businesses the interviews were conducted in English, however when interviewing customers for resource-based products often the interviews were conducted in Twi. This meant that the entire construction of the narratives and conversations with research participants passed through the conduit of my research assistant. There were some challenges with this as the local university specialised in science and technology, so whilst there was a mutual understanding of the problem from an engineering point of view he had rarely engaged in social research beyond closed questionnaires. I think this combined with my grounding in positivism often led towards a focus on quantity of interactions and not quality with often not enough reflexive thinking on the ground and only in hindsight.

A lot of the aspects of his position were similar to mine, in the way that he would project confidence about the research. In the early stages of the research he would occasionally overstate the benefits of certain technologies, for example responding that waste-reared tilapia would not cause any illness without translating the interaction for me. I think this is simply a by-product of his interest and engagement in the subject and a desire to see something be done. As the research progressed these issues were less prevalent as I made it clear that we were not aiming to

convince people of different solutions and that I wanted him to translate all dialogue as what he may perceive as off-comments and tangential pieces of information could be valuable.

I think at times my research assistant also saw working with me as an opportunity in the long term. A lot of this may be down to the fact that my presence, combined with assistant from my local supervisor provided me with access to local government workers and sanitation businesses that he may not have been able to approach himself. For instance whilst trying to meet a local government member from the lands registry to try and get an idea of the sizes of the ponds and surrounding area he also had the opportunity there to ask about an issue that his mother was having with land ownership, which he may not have been able to do by himself. At times he also seemed to partly envisage that I would be coming back to build a biogas or composting plant. This is something that was clear in our conversations at times where he was wondering what the aim of my research was if not to eventually set up my own business or build a treatment system. He also often spoke of how academics and students would get big money when a large sanitation project came in partnership with a university so clearly if the research we conducted was successful he saw that there might be potential personal benefits for himself. This may have also provided another source of researcher bias as his own hopes to be part of a future project influenced how he projected the research to participants and then how he projected the results back to me.

4.6.6 Language

Whilst I managed to learn some basic twi before going to Ghana I was far from being able to speak it at a conversational level. Even this was hugely beneficial in my research in terms of being able to break the ice with people, and show people that I cared. Being able to introduce myself, my university and my research was very good when starting interviews with stakeholders such as government workers or businessmen.

Whilst the benefits of the small bits of twi I could speak were clear, the drawbacks of my limited ability are quite large on reflection. The first considerations of the language barrier are considered previously when looking at the relationship between me and my research assistant. Whilst our working relationship developed over time and he came to understand more what the aims of the research was and thus

translated more fully and properly, it is still clear that all the research I gathered passed through him.

The main other constraint that language placed on the research was in terms of research methods. Due to a combination of the research assistants base in quantitative survey-based methods, time constraints for his own research and logistical the dependence on a translator meant we often were working in an extractive method and observation and more ethnographic methods were not possible to understand how people live and interact. The areas of nuance that seem most obvious for me missing opportunities are:

- Not being able to spend time observing with vacuum truck operators/treatment operators/toilet operators and building a deeper understanding of their job and context
- Not spending informal time with people to understand who makes decisions on fuel/fertiliser/food purchases, how people use products
- Not being able to have less structured environments with farmers and less educated people who were not hugely open/conversational in individual interviews
- Not being able to simply spend time in the communities that solutions are designed for and to try and build relationships

4.6.7 Religion

An example I had not considered of research covered in Greens book 'How change happens' (Green, 2016) is the successful working with different groups or people who are placed to change things in the communities. The main example he cited was a reluctance at time to work with faith groups as an atheist. I think this is something I was also guilty of in my time in Ghana which is slightly negligent considering the role of the church in the society. For the first two weeks in my research I had been woken up at 5:30am by students of a specific church group shouting and banging pans. When I was visiting the person running the halls another student came into complain so I, somewhat awkwardly, joined the complaint and said how loud they were. Nothing much was said in response. Then on Sunday when I went to my one and only church service of my 3 months there, at the end of the service the preacher took a second to take the students to task and tell them to stop making noise, as other people go to different churches at different times so they need their peace to be able to study. From then on the problem did not exist. In

hindsight my ignorance of such a powerful community point seems slightly childish just because of my own beliefs. On the one side it may have provided a view into how people organise theirselves, how a lot of problems and issues are discussed in the community, but it may also have given me access to some people who have significant roles in their society outside of the political theatre.

4.6.8 Research Objectives

Whilst in most interviews people seemed to be open to discussing their issues with sanitation services in Sunyani occasionally my motives were questioned along the lines of *'why aren't you researching water/solid waste etc'.* It was not a question I was hugely prepared for answering at the time and it is only after that I have begun to reflect on the implication of it. I think a lot of the research was grounded in literature review around the whole of Sub-Saharan Africa and 'expert' interviews with NGOs to try to define a specific aim for the research. I think it is difficult to enter an area and simply plan to research whatever problem seems most pressing, but a broader look at sanitation in Sunyani and a grounded analysis of local problems may have made the research more collaborative with communities. Though a lot of the problems that the research planned to investigate existed and were cited as constraints by many stakeholders, perhaps it was not the most urgent of FSM in Sunyani. In most research contexts, I would be satisfied to be conducting research that simply constitutes part of a larger research body assessing whole infrastructures, but in Sunyani this was less true and perhaps devoting time and research to a prescribed idea of the technical problems, specifically that treatment is the main issue, was again following an extractive research process. The clearest example of this is the issues cited in Odumase with public toilets causing whites. From the responses, it could be argued that any treatment model with resource recovery would be dependent on first building peoples trust in the sanitation services so looking at how public toilets spread, or are perceived, to spread diseases would be a clearer objective in a 'grounded theory' approach. Due to time constraints and an existing set of research objectives I did not spend a lot of time trying to understand this phenomena, only noting it in the context of social acceptance of biogas. At times, I feel this approach is slightly imposing of my own approach and beliefs on a local community to tell them what their problem is and then ask them to help contributing to solving it through sharing their stories with me. Undeniably the failure of treatment is a large issue but there could potentially be a simpler set of interventions that are more suited to the limited funding of a PhD research topic that

could be applied if the issue of public toilet hygiene had been looked at in more detail.

I am also slightly wary that the initial focus on ‘community-owned’ design solutions favoured too heavily in research is an imposition of personal values on different cultures. With the aim of the research being simply to establish whether faecal sludge treatment could be self-regulating then ownership and operation should simply be a matter of pragmatism based on the varying institutional capabilities of different options and their suitability to technical models. For instance, aquaculture was low-investment, low-income and therefore would not be attractive to private sector but potentially may be attractive to an individual entrepreneur while biogas production on a large scale requires large amounts of operation and capital investment suited to bigger business or government. I think the internal preference for a community owned operation is potentially an example of idealising slum mentality (Ayee & Crook, 2003). With the difficulty of finding existing entrepreneurs in sanitation, and even being able to verify what or how much of a role they play in provision, it seems an oversight to ignore the reality that most services are provided by large companies and institutions. Whilst I tried to stay more open, and if anything due to better access leant towards researching companies more, the risk that the combination of a narrow preset research question and method of ownership is somewhat marginalising to the communities I had intended to help.

4.6.9 Considerations for Future Methodology

I think from speaking to stakeholders, personal interviews, and the increased aid dependence of the country, I expect the aid dependence narrative to be even more prevalent in Malawi which needs consideration for how to approach the case study.

The main aspect of the research that I feel inhibited the process was my accommodation and location within the research. This is mainly exhibited with the interviews with farmers and fish farmers where I was forced into a far more extractive relationship than I could manage in the city where I was spending most of my time. Depending on the time availability and access I can gain, I think one of the research design considerations should be to maximise the time I can live with the different communities needed to research instead of basing myself in one area. This would also allow me to spend more time observing the day-to-day realities of fish farmers and farmers rather than simply relying on interviews that at times some people did not seem entirely used to participating in as a research method.

I think whilst I entered Ghana with a desire and awareness of the challenges to social it was quite easy to get knocked off path either by logistical, personal or physical difficulties with experiencing peoples' lives. I think in future case studies I need to spend more time focusing on how I actually integrate myself within a community than on methods as such. The following quote from Willis (1981) can indicate the pitfalls of spending too much time focusing on methods and methodology:

'It is customary… to say something about what is somewhat pretentiously called "methodology". My field method could be summed up as meeting people'

Whilst I would also want to spend a lot more time observing and there are still some real-world positivistic data to collect on the whole I would like to change the approach to focus on understanding the context more. I need to consider this as a balance as to how much I can personally manage, how long I can spend in the areas and what approach this takes.

5 Mzuzu Case Study Analysis

5.1 Section Structure

This section lays out the results from the case study conducted in Mzuzu, Malawi. The section is set along the framework for identifying suitable designs and models in Figure 4-1. Based upon the reflexivity after the Sunyani case study, a consideration of the methodology is discussed in 5.2 with changes made where possible. Then the potential of existing faecal sludge reuse approaches in Mzuzu are analysed in section 5.5 before concluding on the viability of resource recovery and then the methods and approach of the research and its implication for the results are reflected on in a reflexivity section.

5.2 Reflection on Sunyani Approach and Adopted Methodology

The main aspects of research in Sunyani that suggested a need to adopt the research approach to improve results were:

- The environment and stakeholders being quite different to what the research had anticipated forcing adaptation of research focus and approach
- The difficulties understanding the political relationships in management of sanitation
- Misunderstanding of research participants expecting to gain technology
- Misunderstanding in communication with translators
- Extractive Nature of Research

A lot of the initial experience of Sunyani had been contrary to what I was expecting. A lot of the research literature and informal interviews in the review had been about small scale entrepreneurs as service providers in poor cities, and often about slum areas that are difficult to access. Whilst I had acknowledged that there was very little literature about Sunyani, my inclination had been expecting a similar trend. What actually existed was more of a private sector monopoly, or duopoly on septic tank emptying and public toilet emptying. This meant that a lot of what I had tailored my research towards, and a lot of the problems I had anticipated being crucial to sanitation as an engineering problem did not exist in reality when I arrived requiring some changes to the research. For the research in Mzuzu the methodology was designed to be much more flexible, with a time period open to stakeholder interviews and exploration before defining a rigid methodology of who to speak to and what questions to ask. This was anticipated to allow for informal conversations

to build up a picture of what the crucial areas for development were before starting. This also allowed an exploration of the city whilst waiting for ethical approval from the government in Malawi, which led to a waiting period where data could not be collected but where I could observe the city and talk to people informally to build an idea of the key points of investigation. This contrasted with Sunyani where due to funding and personal time constraints I 'jumped in' more than was suitable.

One constraint that emerged from my research in Sunyani was the time limitation meaning that I did not fully explore or understand the relationship between the private sector and the government and the relationship between them. This felt limiting in being able to understand the implication of any model suggested, particularly if it requires large investment or a centralised management model between the government and the private sector. The main solution to this issue is simply to provide more time for research, spending longer durations being able to spend more time with key stakeholders and observe them more. The limitations of funding and time for the Mzuzu case study meant that it was difficult to really get an in-depth view of how they interact. Instead more provision was made for repeated interviews and meetings in the hope that it would build the relationship more and expand the discussions. It was also hoped this would allow the opportunity to get more than a one-shot view of the key stakeholders and instead discuss aspects of the research with them as my understanding of the city grew throughout the research giving a richer discussion. For this more time was set aside for speaking and meeting with stakeholders on repeated occasions where possible.

In Sunyani in both the relationship with the research participants, and the translators and research teams, there was often a lack of clarity. Sometimes this led to translators interpreting results or describing aspects differently, or with participants expecting to receive technology as part of the research. To mitigate these issues in the Mzuzu case study, the research made a plan to spend a longer time with the translator and research team being clear about the purpose of the research and role. More time was devoted to discussing as the research went along to ensure that the results that I was understanding as they were translated were similar to that of the translator. With research participants, each participant was briefed about the purpose and aims of the research in more detail and checked that they understood, as well as repeating this at the end to ensure they were still not in any doubt about the purpose of the work.

The extractive nature of the research in Sunyani was an issue again, with often very short visits and little feedback afterwards. This also came down to the location of accommodation, time constraints of research and language limitations. Some of the limitations remained for the Mzuzu case study due to the time constraints, lack of accommodation options that could be accessed quickly, and lack of language resources to learn before. The only change that could be planned was to try to spend more time out and in places where I would meet people around the city, though this had its limitations from language meaning attempts rarely enabled any conversation but did breed a familiarity with people in the area.

5.2.1 Final Adapted Methodology

The initial stage of the research was spent assessing the infrastructure in Mzuzu, stakeholders and different forms of reuse that have been implemented and could be scaled up. Based on the greater acceptability of reuse in agriculture, the projects that have tried to implement composting toilets and the fact that the government were rehabilitating the treatment site to produce compost the research focused on understanding the successes and constraints of existing approaches to reuse in agriculture.

Surveys were conducted by the University of Mzuzu and the data was shared with the author, as it closely correlated with my planned methods so it was deemed more efficient to use the results already collected. 148 participants were sampled purposively and asked about their sanitation services, awareness and perceptions of services and potential for re-use of faecal sludge in energy or agriculture.

Interviews were conducted to look at the existing forms of faecal sludge reuse in Mzuzu, which are household composting toilets and application of sludge from the central treatment site. The central treatment site mostly receives waste from formal settlement areas and institutions with septic tanks, due to the difficulties of emptying pit latrines in informal areas. Skyloos were introduced to improve household sanitation and provide compost for households that had previously relied on unimproved pit latrines. They were implemented by 5 different projects from 4 organisations that targeted population sections, financed the toilets and trained users in different ways, shown in Table 5-1.

Semi-structured interviews were conducted with users who had composting toilets (n=47) and farmers who applied faecal sludge (n=11) from the disposal site in

Nkhorongo to understand the issues surrounding reuse in Mzuzu. Key Informant interviews (n=7) were conducted to understand the roles and challenges for NGOs, businesses and the local government ensuring proper sanitation services.

Skyloo users were asked about how they had been introduced to the technology, how they had financed the purchase of the toilet, and how they found the use of the toilet and compost. Farmers who used faecal sludge from the treatment point were asked about how they used it, difficulties with access to the sludge and how it compared to normal fertiliser. Research participants were found using snowball sampling starting with a few initial known sites where there were Skyloos or farmers using untreated sludge.

Farmers using untreated sludge in agriculture were selected until the snowball sampling led to the people who had already either participated or not consented to the research. Skyloo interviewees were chosen from all the known projects installing Skyloos in Mzuzu with a sample of between 5 and 15 interviewees from each depending on the number of people each project served and ability to find interviewees by snowball sampling.

Project	Financing Approach	Material Contributions by User	Sensitisation Approach	Targeted User	Year of Project
1	100% subsidised by donor	No	Presented different options then built chosen technology	Urban families of orphaned children through faith based organization	2014-15
2	Loan for house and Skyloo combined	No	Provided standard house and sanitation design	Urban poor	2010
3	Loans to households	No	Marketed Skyloo technology in	Urban residents	2010-2016

	from donor fund for urban development		areas and provided loan for construction		
4	Loans to households with donor collateral	Bricks and sand and optional further contribution	Marketed Skyloo technology in areas and provided loan for construction	Urban residents	2012
5	Loan for house and Skyloo combined	Mudbricks	Provided standard house and sanitation design	Urban poor without housing	2007-2010

Table 5-1: Different Approaches to Implementing Skyloos

5.3 Political and Social Context of Malawi

5.4 What is the existing sanitation infrastructure and who are the providers

Key areas of Mzuzu are indicated in Figure 5-1. There are less public toilets to indicate and they are not as important in terms of infrastructure as in Sunyani so are not shown. The areas where skyloo users were interviewed are indicated, mostly they were near to waterlogged 'dambo' areas. The treatment site is towards the North of the city in Nkhorongo area. It is not in the same location as the solid waste disposal site, which is currently being built to the west of the composting site.

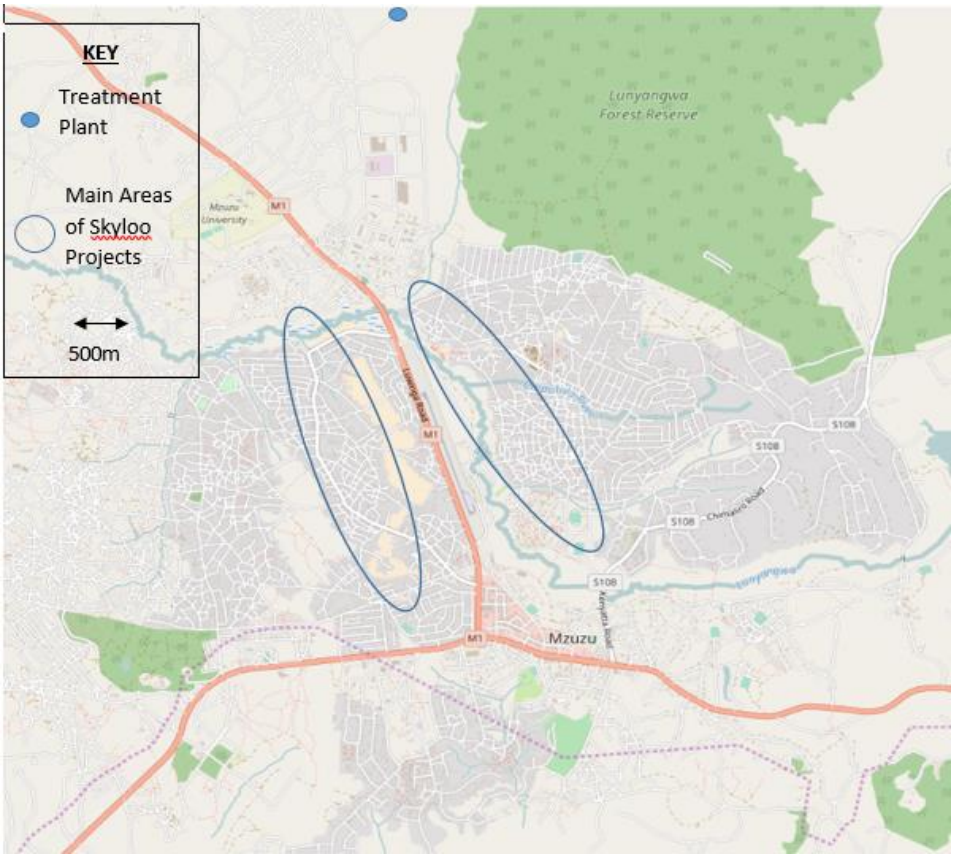

Figure 5-1: Map of Mzuzu Research Areas and Treatment Plant

5.4.1 Household Sanitation

Household sanitation in Mzuzu was found to be poor overall from the interviews, surveys and literature findings. In terms of looking towards re-use of faecal sludge there would be a need for intervention at the household level for most of the population. The majority of the population relies on private pit latrines for household sanitation, with around 9.9% of the population using water borne toilets (Mzuzu City Council, 2011). Open defecation was cited as an issue in Mzuzu. There are a limited number of public toilets in market areas and institutions but they are not used to the same extent as in Sunyani. All survey participants had a private toilet facility with 147/148 participants using a pit latrine and one participant using a septic tank. Toilets were shared between groups of ranging size up to 15, with an average of 6.5 people sharing a pit latrine. 86% (128/148) of the research participants had not had their pit latrines become full. Of the twenty households who had experienced their latrine becoming full, 11 were in Zolozolo, 5 in Mchengautuwa and 4 in Chibavi. Only one participant in Chibavi had emptied their pit latrine when it became full, as it was an ecosan facility so they manually emptied it their selves. The rest built a new

latrine when theirs became full instead. This represents an unsustainable solution in the long term with the density of the areas and increasing populations likely to place a larger burden on space, and the latrines often eventually causing groundwater or river pollution (UN Habitat, 2011).

5.4.2 Collection/Transport

There is a large business responsible for emptying septic tanks and latrines in the city, and there are pit emptying services from informal entrepreneurs. Mostly residents will currently abandon a latrine and build a new one at the end of its lifespan rather than using emptying services. It is currently unclear how many other providers there are in the city from the interview with an existing emptier:

In the past, there were three people who were also offering the same services of pit emptying but as of now am not sure whether they are still doing the work. People are afraid of bad smell from the pit latrine.
(Pit emptier, male)

The road network in Mzuzu was also limiting for the transport of faecal sludge. Transport issues begin at household level in informal areas where there are often poor road networks, particularly in rainy season, that can prevent access for emptying services to latrines:

"The other challenge is in Masasa and places is actually accessing for desludging as the roads are small and difficult. The cost of desludging also can be between 40,000 Kwacha and 50,000 Kwacha."
(Key Informant, Male, Project Manager at NGO supporting FSM in Mzuzu)

The road network leading to the disposal site is also poor which can prevent the safe disposal of faecal sludge for treatment:

"I would try to carry to dump site but everything was falling off with the roads and people stoned me and the children would be shouting 'mr you carry shit'"
(Septic Tank and Pit Emptier, Male)

"There is need to … maintain the access road which needs improvements as there are many bumps and humps and sludge is so heavy so it can damage the vehicle."
(Key Informant, Male, Technical Advisor at NGO supporting FSM in Mzuzu)

5.4.3 Treatment

Mzuzu had a composting site for faecal sludge in Nkhorongo, with two pits that are used for drying the sludge and eventually selling the compost produced. At the time of research the site was being rehabilitated after becoming run down, and had not been used for a long time for disposal or treatment. Often the emptiers were dumping sludge elsewhere, citing the high dumping tariff and value of sludge for re-use as a driver for this behaviour. When sludge was legally disposed at the site it was often taken by farmers in the area either in agreement with the guard or when the guard was not at the site. This led to the treatment site being empty often. The future rehabilitation has a permanent building for a guard and fence to keep out farmers to try and improve the management. The rehabilitated design is based on two drying ponds that can be used in alternation and then the remaining sludge will be sold as compost by the city council.

5.4.4 Faecal Sludge Flow

There was a similar issue as in Sunyani with assessing sludge flows to the treatment site in Mzuzu. Due to the prominence of illegal disposal and the lack of emptying by many latrine owners it was hard to know how much sludge is collected in total. From interviews with the government and mr clean it is estimated that there are around 60 trips a month overall whilst the private sector estimated 30,000 litres a day. Currently most of this is not being collected at the treatment plant as was observed with the empty site during the research and by other research before. Considering that most of the population does not currently use faecal sludge emptying services there is a potential for the collected faecal sludge to be much larger.

5.4.5 Reuse Options and Their Suitability to Mzuzu

5.4.5.1 Biogas

Biogas has been implemented on small scale systems in different areas in Malawi, but usually with the intention of producing gas from animal excreta instead of human waste. Whilst in Sunyani large sections of the population used gas for household fuel and some cars also used gas for fuel, Mzuzu's population mostly used coal or wood for cooking. Producing biogas for household use would be a more difficult system to implement due to the reduced amount of people already using gas canisters that could be adopted for biogas. There are issues with electricity production and blackouts in the city which may make a viable case for biogas being

used to generate electricity. Whilst it may not be suited to a city wide implementation there were some projects looking at producing biogas for institutions like schools where the fuel would be directly used for cooking.

5.4.5.2 Aquaculture

Aquaculture was not considered as a viable option for reuse of faecal sludge in Mzuzu, as the existing treatment systems are not suited to retrofitting aquaculture so any model would require building a new treatment system. From interviews with people who have worked in aquaculture this would make the economic case for aquaculture re-use unfeasible. For this reason, people's perceptions of aquaculture were not investigated in the case study.

5.4.5.3 Fuel

The reuse of faecal sludge as a fuel for cooking was being started in Blantyre, the commercial capital of Malawi. This involves the production of briquettes from organic food waste and collected faecal sludge in the city. The project was in pilot phase in Blantyre so it is not yet clear how well they perform and how people feel about using them. The technical possibility of low cost briquette production led the research to investigate perceptions of reuse of faecal sludge in fuel.

5.4.5.4 Compost/Fertiliser

The central treatment plant in Mzuzu is intended to produce compost from collected faecal sludge and sell to farmers, though in its current state it has not been operational. There have also been projects implementing composting toilets in urban areas where users then apply the compost on their own farms or sell it to local farmers. As the production of compost is being pursued and implemented by the local government, with investment funding already put into the rehabilitation of the treatment system, the potential for scaling up of re-use in agriculture is the main reuse option investigated in the case study.

5.5 Constraints and Opportunities for Reuse of Faecal Sludge in Agriculture

Table 5-2 shows the different barriers to FSM in Mzuzu identified during the research, which are explored with additional data and information in 5.5.1-5.5.6.

Stage of FSM Chain	Physical/Environmental Barriers	Financial Barriers	Political Barriers	Social Barriers
Household Sanitation	1. Latrines often flood or collapse	2. People struggle to afford improved sanitation without finance source		3. Lack of awareness of products 4. Landlord-tenant relationship often leads to tenants using pit latrines 5. Skyloos not suited to poorest and physically disabled 6. Abandoned projects reduce trust in community
Collection	7. Poor access to some informal areas 8. Poor road condition approaching treatment site			9. Lack of awareness of services

Transport		10. Private sector dump elsewhere to avoid fees	11. Council unable to enforce safe disposal	12. People often shamed for handling faecal sludge
Treatment	13. No fence to prevent access	14. Disposal tariffs deter businesses from safe disposal 15. Tariff not based on volume can have effect for smaller customers at household level	16. Unable to prevent stealing of sludge and public walking through site 17. No direct management of funds for maintenance	18. Guard does not have facility or authority to collect fees 19. Difficulty enforcing rotation of ponds
Reuse	20. Transport of manure is heavy and expensive	21. Unclear financial value of product	22. Reuse unsuited to poorest and disabled members of society	23. Disconnected market for selling compost 24. Limited awareness in how to apply in agriculture

Table 5-2: Barriers to Faecal Sludge Management in Mzuzu

5.5.1 Perceptions of Household Sanitation

The main issues with the standard unimproved pit latrine used by households in informal areas in Mzuzu are high groundwater, lack of space for digging new pits and short life spans before either filling or collapsing, as identified in point 1 of Table 5-2. Out of the 128 households who had not experienced their latrine becoming full, around half (61/128) had been using the facility for a year or less.

One issue that was mentioned by participants was that of latrines collapsing due to the high water table. Two of the participants who had built a new facility after theirs had become full said that they did not expect their new facility to last very long for this reason. Most participants expected their new latrine to last less than a year (14/19), showing the effects of living in settlements that mostly lie on a high water table (Mzuzu City Council, 2011).

Looking at the location of latrines and the expectations of collapse, expected life of new latrines and length of use without filling, there is potentially some correlation between low life expectancy and geographical location. Chibavi and Mchengautuwa are bordered by streams which have swamp or 'dambo' areas surrounding them. The drainage from the roads and the surrounding areas near these dambos is often poor, with the roads inaccessible in heavy rains. The complaints of latrine collapse and expectance of latrines to fill within less than a year was quite common in the areas near these streams in Mchengautuwa and Chibavi. The issue of houses being built in close proximity to dambos and streams is less prominent in Zolozolo, but the steep slopes and individual latrine design may be more of a factor.

From interviewees who had adopted skyloos the issue of space for new latrines and flooding or collapse was a big driver for adoption. 18 interviewees mentioned the benefit of manure as a driver for adopting Skyloo technology whilst 35 mentioned either flooding or space, with 27 citing the permanence of the technology and 18 mentioning flooding:

"There is a big difference in terms of the land use. With pit latrines I have to build another and another depending on the water level. This is a huge problem here as the water is very high. I have another plot nearby with a pit latrine with issue"
(Ecosan User, Project 3, Male, 65)

"There's a big difference. Firstly I don't have to use lots of land as I have used much land digging many latrines in the past. Behind my house I have had to dig many different spots as they fill. There is also the benefit of harvesting manure"

(Ecosan User and Loan Collector, Project 3, Female, 62)

5.5.2 Pit Emptying Services

One of the main issues, in point 9 of Table 5-2, that was clear from household participants and pit emptier interviews is that a constraint to pit emptying services in Mzuzu is a lack of information. Of the participants that did not use emptying services when their latrine filled, the main reason was that they were unaware of services, as shown in Figure 5-2. It is unclear how many of those had an unlined latrine that emptiers would not service anyway. A study of pit latrine strengths in 3 other urban settlements in Mzuzu found that a minority of the latrines were lined, with 15 out of 300 sampled latrines being lined (Chirwa, et al., 2017). The two respondents who found pit emptying services to be too expensive constructed their own latrine rather than paying for a mason, which is likely cheaper than the 30,000 Malawian Kwacha (MK30,000 = USD41.40) charged.

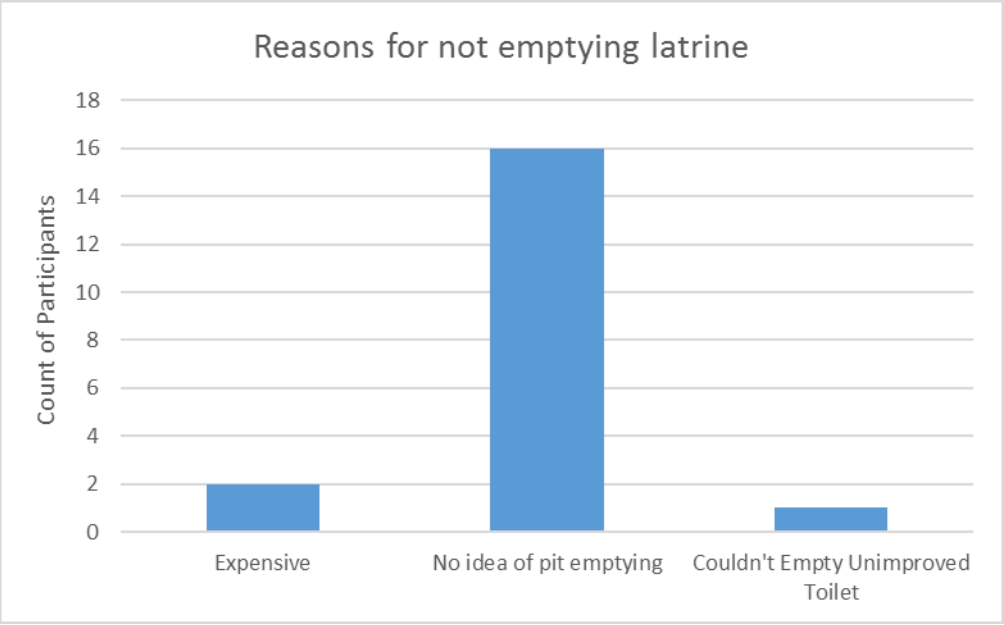

Figure 5-2: Reasons for Not Emptying Latrines in Mzuzu

5.5.3 Perceptions of Reuse Options

Survey respondents were asked about whether they would be open to reuse of faecal sludge in agriculture, or in energy and their reasons for wanting to use or not. Around half (78/148) of the respondents were not open to the reuse of faecal sludge

in agriculture or energy, whilst agriculture was the most acceptable resource as 64/148 respondents were open to using whilst 36/148 were open to the idea of using faecal sludge for energy.

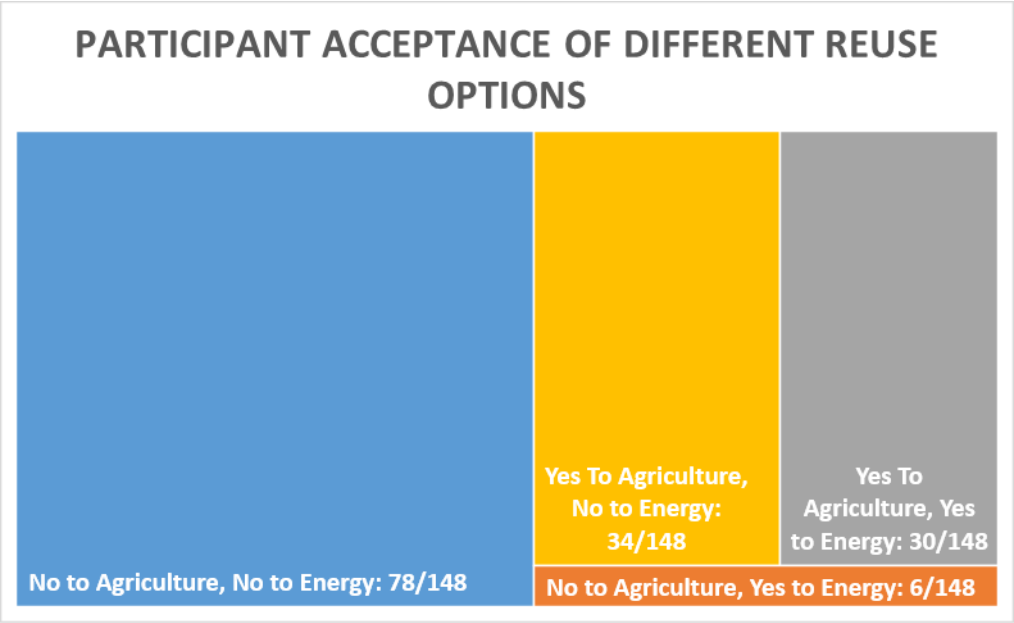

Figure 5-3: participant acceptance of different reuse options

As shown in Figure 5-4, the main reasons people cite for using faecal sludge in agriculture relate to replacing fertiliser with a cheap alternative, the quality of manure and its ability to increase food yield and the possibility of being able to keep using the same pit latrine. It was common in all the settlements studied that people would have small patches of subsistence land that they grew maize on, which may be suited to the use of direct composting with ecosan and then application on nearby land without large distance transport of faecal sludge which can often be a challenge in FSM (Chowdhry & Kone, 2012), and formed the largest component of costs for the pit emptier.

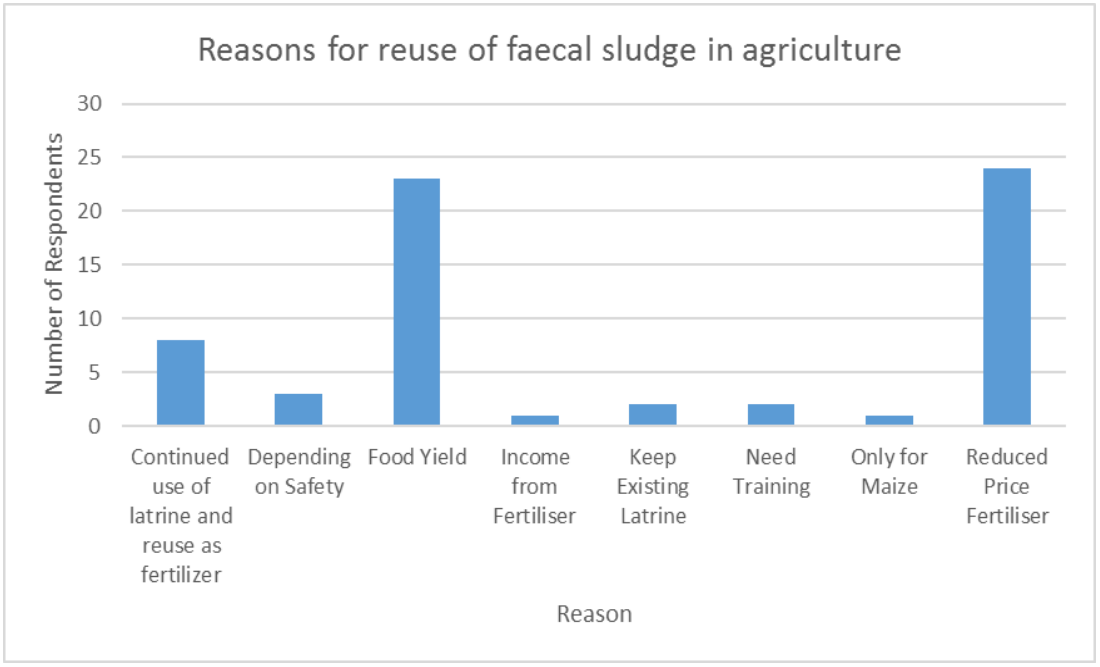

Figure 5-4: Chart of Reasons for People using faecal sludge from agriculture

A wider variety of reasons was given for those not willing to use faecal sludge in agriculture. Of the respondents who would not use faecal sludge in agriculture the main reasons given were hygiene concerns (44/83) and unawareness of the product (20/83). More reasons given were not having a farm to apply fertiliser on (6/83), too much work to use ecosan (3/83), apprehension around using/interacting with faeces in any way (3/83), not decisionmaker (2/83) and other individuals cited bad quality of human manure instead of animal manure in agriculture, bad smell, high water table preventing drying of sludge and latrines never filling as reasons not to use agriculture.

People who were open to use energy produced from faecal sludge were mainly open to the idea of having a cheaper fuel (9/36), an easier to source fuel than charcoal or firewood (10/36), and reducing the need to cut trees for fuel (6/36). A few others saw the potential as a lighting source (3/36) or an alternative source of electricity (2/36), whilst some would be open to the idea if it was demonstrated to them (3/36).

The main reasons against using faecal sludge for energy was mostly that of a lack of knowledge of the product. This is the main difference between perceptions of energy and agriculture from participants, with only 20/148 participants not being aware or sure of the potential use of agriculture whilst 60/148 were not aware of the

potential use of energy. Otherwise the concerns surrounding hygiene and use of human waste are fairly similar.

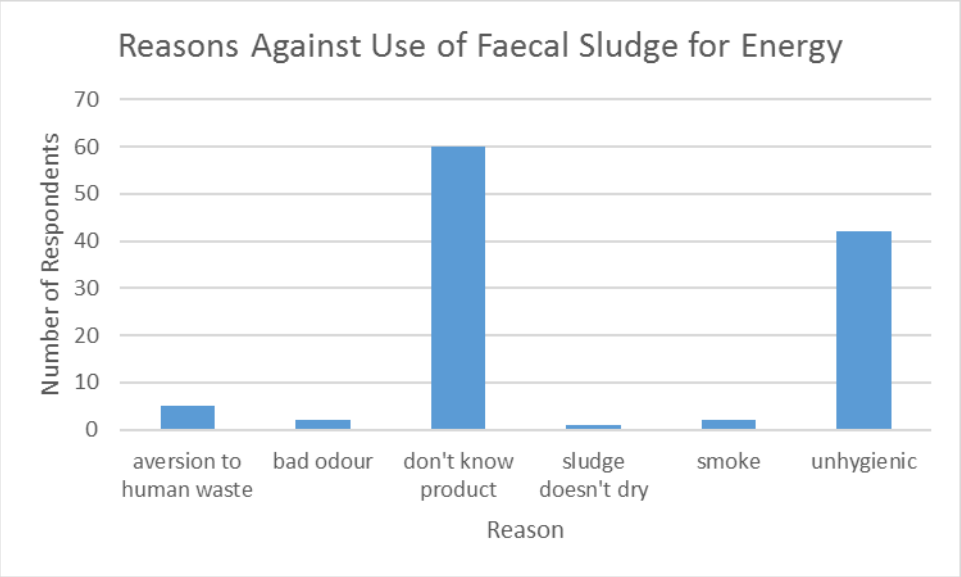

Figure 5-5: Reasons against Use of Faecal Sludge for Energy

5.5.4 Constraints of Sanitation Sector

5.5.4.1 Sanitation Marketing

This section refers to points 3 and 9 in Table 5-2. In our study, often respondents were not aware of different sanitation services and providers in the city. Not knowing of reuse and pit emptying options were the main reasons household respondents gave for not using services. No survey participant had used pit emptying services before, with 16/19 of households who had previously had a pit latrine become full not emptying because they were not aware of available services. 64/148 participants were open to the use of faecal sludge in agriculture, and 20/84 respondents who were against the idea cited unawareness as the reason. This lack of awareness can also be seen from the business side, with pit emptiers rarely promoting their services:

“Am well known for what am doing and people send the messages through relatives whenever they have a pit latrine that needs to be emptied.”
(Manual Pit Emptier, Male, 42)

In terms of adopting new technologies and reuse of faecal sludge, a common theme was being informed by project based marketing campaigns:

"So I first heard from (Project 3). From them I heard about these toilets that are taking less land and can harvest manure."
(Skyloo User and Loan Collector, Project 3, Female, 62)

"*The main issue they came with when selling was that there was waterlogging and pit latrines were collapsing in the area so they were telling us we shouldn't be using pits."*
(Skyloo User, Project 3, Male, 65)

Implementing household sanitation that can either be emptied to the composting site or used for household compost would require marketing from businesses and NGOs to be successful. There were no cases found of Skyloo adoption through word of mouth after projects ended.

5.5.4.2 Transport

The existing transport infrastructure was cited as a constraint to current approaches to faecal sludge re-use in Mzuzu, linked to points 7, 8 and 20 of Table 5-2. Transport issues begin at household level in informal areas where there are often poor road networks that are difficult for vehicles to access:

"The other challenge is in Masasa and places is actually accessing for desludging as the roads are small and difficult."
(Key Informant, Male, Project Manager at NGO supporting FSM in Mzuzu)

"I would try to carry to dump site but everything was falling off with the roads and people stoned me and the children would be shouting 'mr you carry shit'"
(Septic Tank and Pit Emptier, Male)

People who had adopted Skyloos also found transport to be a constraint to the re-use of compost as their farms were often in other areas or on the periphery of the city:

"In terms of transport for the manure as it is heavy and my farm is in Zolozolo so difficult to have everything ready constantly carrying with a bike"
(Ecosan User, Male, 42, Project 5 Mchengatuwa)

Transport was also a big challenge for farmers who were taking sludge from the Nkhorongo treatment ponds and applying in agriculture. Of the 11 interviewees, 10 were subsistence farmers and most carried the sludge manually walking with one farmer using a bicycle and 9 cited the issue of transporting sludge as a challenge.

"There are accessibility problems especially in rainy season because it's very heavy to carry while in dry season it is easy to access but now more difficult"
(Farmer applying raw sludge, Female, 66)

"Transport is the main issue as I have to carry but if I could transport to here I could maybe use the sludge here also"
(Farmer applying raw sludge, Female, 52)

The issues with transport show that in informal areas it can be difficult to access and empty pit latrines. In areas like this the Skyloo may be a more suitable solution to scaling up reuse, but there would need to be land where compost could be used.

5.5.4.3 Taboo of Re-Use and Handling of Faecal Sludge

This section relates to point 12 of Table 5-2 and the issue of the taboo around faecal sludge emptying, handling and re-use in many areas:

"I'm concerned that they (tenants) would not like the idea of it and using ash and things so instead I made a latrine at the back. The positioning of this one is also not good and is close to the house. Maybe could discuss with them to see how they would feel but I'm concerned they wouldn't like it."
(Ecosan User, Project 1, Female, 59)

The lack of discussion or spread of ideas was also shown when Skyloo users from project 4, where the organisation had promised to find a market for Skyloo compost, had to find a market their selves. Most found a method to sell their manure but one user could not despite being in a savings group with the others:

Interviewee: *I have done it before (emptied) 4 times now but when they built they promised they would find a market for us but now I have to dig pits myself and bury the waste each time and I'm running out of space to dig.*
Interviewer: *Have you consulted anyone else with ecosans?*
Interviewee: *No I haven't done. But most of them are doing the same as me*
(Ecosan User, Project 4, Male, 60)

There was also a taboo around the re-use of faecal sludge from Nkhorongo sludge ponds, with people feeling ashamed to be handling faecal sludge:

"So the moment the waste comes in people come to get it and people look down on you and with shame. See we have to go without gloves or gum boots and we feel it too but it is a need so it has to be done"
(Farmer using faecal sludge, Male, 35)

The issue of the taboo around sanitation can also be seen in the issue of getting people to work in the sector and skilled people entering the market:

"Well with sanitation no one likes to talk about it. They think I shouldn't be doing. People resent it so can be difficult getting right people to do it and concept is new."
(key informant, Male, worked with project 4 and has sanitation business)

"Even my own mother when she found out she said that when I will die my legs will swell.... I had to change church because the pastor denounced me. I stopped for a while because of the shame."
(Septic Tank and Pit Emptier, Male)

This taboo often leaves a fractured market in terms of information which can provide a barrier to services scaling up across the city if there is a difficulty for ideas to spread. This means that projects may not develop beyond the scope of who they can directly market to which suggests large marketing costs to spread technologies.

5.5.4.4 Scope and Application of Compost

Whilst the survey responses and interviews knew that faecal sludge had nutrient value, there was a gap in knowledge about the nutrient quality and health risks identified in points 21 and 24 of Table 5-2. This meant that people had varying methods of application and market values that they could sell compost for. Some users of Skyloo toilets simply throw the compost away or apply it in small gardens whilst some claim it can support quite large farms:

Interviewee: *I find it good. This season I haven't used any fertiliser and instead just used 10 bags of manure on my 3 acre plot. I apply it same way as 23-21 placing in hole after germinating*
Interviewer: *Did you use fertiliser before?*
Interviewee: *So before on the 3 acres I would use 3 bags each of 23-21 and UREA*
(Ecosan User, Project 4, Male, 65)

"*The benefit is there of course but I am not sure how much to apply as if I apply too much it will not germinate but if it is too little then the crops won't grow heavy."*

(Farmer applying raw sludge, Male, 35)

There was also a varying perception of the risks associated with compost from Skyloo toilets and the risk of using sludge raw from the treatment plant:

"Also needs protection such as gloves for manure as usually people use their bare hands and even if it looks as sand people are still thinking that it is waste."
(Ecosan User, Project 2, Female, 30)

"*The issue is that I haven't used it before and they were supposed to be handling it for us and we don't want to. So now we don't know whether to remove and bury or to use it, don't know if its ok."*
(Ecosan User, Project 4, Female)

People applied the compost with the same approach as they had previously used commercial fertiliser, but with varying quantities. In terms of using sludge from the treatment plants usually farmers took as much as they could transport. The lack of clear value can also be seen in the variation of the price for different sludge-based products in Malawi. Some people reported consistently selling 50kg bags of manure from Skyloo toilets for up to MK6,000 (USD8.28) whilst in other areas some only got a price of MK500 (USD0.69) per bag and before shutting down the Nkhorongo ponds for rehabilitation the government had been selling bags for MK300 (USD0.41). To realistically identify the potential of re-use a better understanding of the nutrient content and market value would be needed.

5.5.4.5 Equitable Access

This section refers to points 5 and 22 of Table 5-2, having found that the current forms of re-use being practiced in Mzuzu are not inclusive designs that achieve equitable access to sanitation. The re-use of faecal sludge from the disposal ponds is physically demanding in terms of transport for people with disabilities to be able to access the re-use of manure as organic fertiliser, with the 12 farmers interviewed having to transport large weights (50 kg+) of sludge manually for use in agriculture. Skyloo toilets also have issues both with being accessible design for physically vulnerable or disabled people and children. 10/48 Skyloo users cited issues of children using the Skyloo correctly with them often forgetting to add ash or divert urine correctly, and 7 users instead let the children use a pit latrine:

"it's ok but somehow it is difficult to use as with the children they get confused. To me I would prefer a pit latrine."

(Ecosan User, Project 2, Female, 57)

The issue of physical strength affecting the tools and knowledge to maintain and use Skyloos was particularly prominent in project 1, where the Skyloos were being built for families that often supported many orphaned children and would be considered ultra-poor. Some of the recipients and family members were also suffering from HIV and too poor to afford basic tools for accessing the back of the skyloo:

"The other issue with harvest is that I am too weak to do it as I have HIV and am elderly so can't open and do it."
(Ecosan User, Project 1, Female, 59)

"*For small children and old people though it is not best. For my mother she fell from the steps once and is still having problems with her knee. But for me there's no problem….. If I see benefits of it I'll use. For now I'll use a pit latrine."*
(Ecosan User, Project 2, Female, 31, Skyloo shown in Figure 5-6)

The physical demands of maintenance for faecal sludge re-use in Mzuzu mean they are currently not working as NGO solutions for the most vulnerable people. For implementing projects that are targeting people with disability and the poorest populations. A handrail option for the Skyloo stairs was observed at one house which may help to assist some people.

Figure 5-6: Abandoned Skyloo next to pit latrine used instead

5.5.5 Implementation and Success of Projects Implementing Skyloos

Beyond the general constraints to the whole sanitation sector that inhibit the development of re-use in agriculture, there are many issues specific to the use of Skyloos. Figure 5-7 shows the themes mentioned by Skyloo users, with the area of the boxes corresponding to the number of interviewees who mentioned the issue.

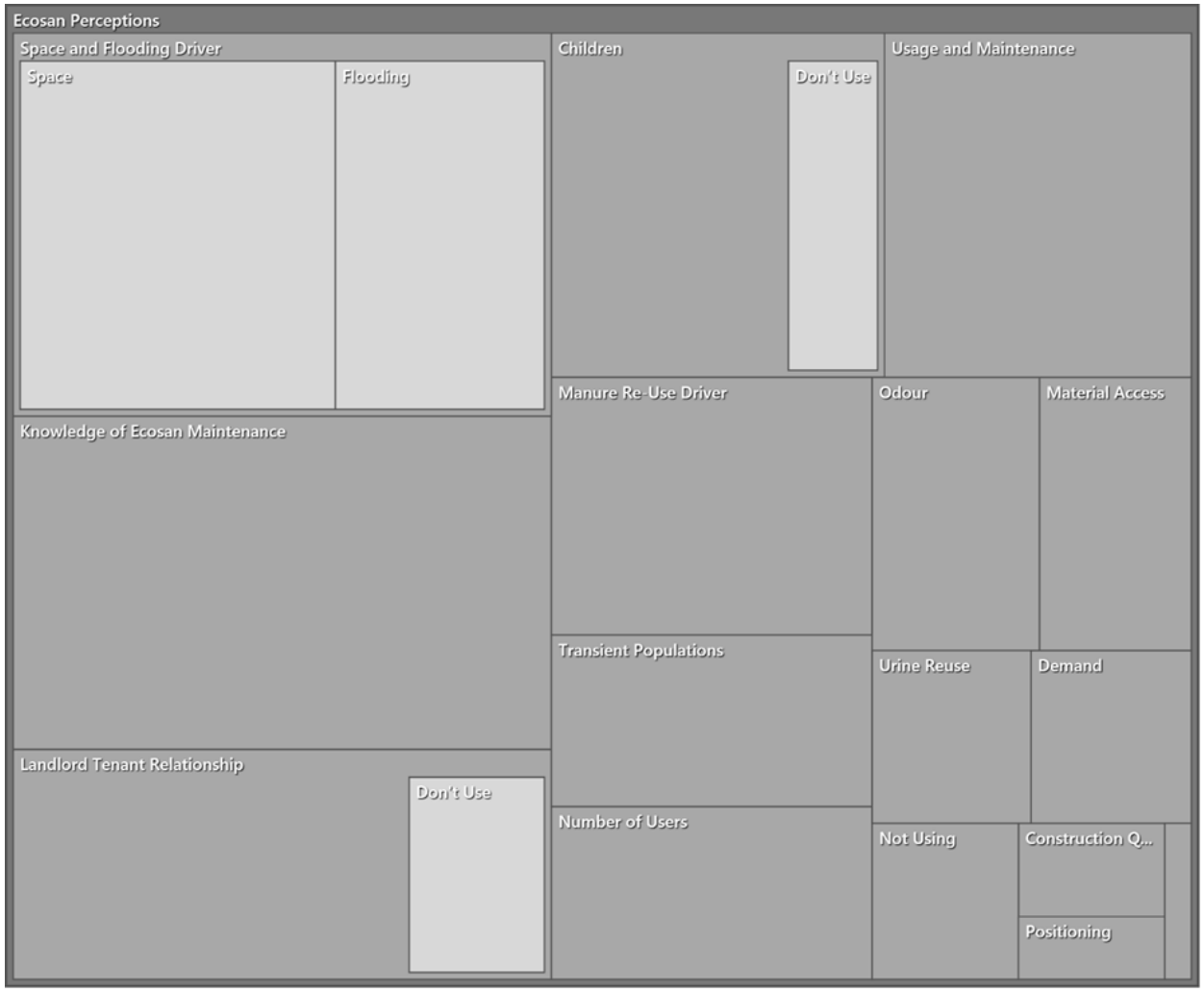

Figure 5-7: Themes mentioned by interviewees about Skyloo usage

5.5.5.1 Financial Constraints

The expense of Skyloos, referred to as a constraint in point 2 of Table 5-2, are a challenge for most people in Mzuzu currently. This has two components: the inflation of the price and the lack of access to finance. Only one user out of 47 interviewees had bought the Skyloo upfront. The provision of financial products allowed people to pay over a longer period making the technology affordable. This current price has also risen from MK35,000 in 2007 through to MK200,000 (USD275.91) now, with some citing higher prices still. Without access to financial services such as loans not many customers will be able to afford the whole price up front, when the minimum wage is MK20,000 (USD27.59) per month and the average monthly income from the 148 survey participants was MK43,200 (USD59.60) per month.

The loans from project 3 were charged at 1% interest per month with donor backing to maintain the revolving fund. The payback period was 2 years. If this system were to be reinstated with the new price of MK200,000 (USD275.91) being covered then a monthly payback of MK9,320 (USD12.86) per month would be needed, 22% of the average income of survey participants. Of the Skyloo users and survey participants who could give data for cost and lifespan of latrines, 5/38 were effectively paying more than MK9,320 (USD12.86) per month for a latrine.

From snowball sampling and key informant discussions it was not possible to find any Skyloo users who had adopted the technology after the projects had stopped, showing both the need for financial products and the importance of marketing from the organisations in spreading the technology.

5.5.5.2 Space and Flooding Issues

The issue of flooding and collapse of pit latrines was identified in point 1 of Table 5-2. For Skyloo users, the issue of space for digging new pit latrines and the flooding and collapse of unlined pit latrines was a bigger driver for adoption than the re-use of manure. 18 interviewees mentioned the benefit of manure as a driver for adopting Skyloo technology whilst 35 mentioned either flooding or space , with 27 citing the permanence of the technology and 18 mentioning flooding:

“There is a big difference in terms of the land use. With pit latrines I have to build another and another depending on the water level. This is a huge problem here as

the water is very high. I have another plot nearby with a pit latrine with issue"
(Ecosan User, Project 3, Male, 65)

"There's a big difference. Firstly I don't have to use lots of land as I have used much land digging many latrines in the past. Behind my house I have had to dig many different spots as they fill. There is also the benefit of harvesting manure"
(Ecosan User and Loan Collector, Project 3, Female, 62)

There are two main implications of this driver for Skyloo technology being more important than manure reuse. Firstly, it means that there may not be a huge scope for the technology in other areas of the city, or other regions in Malawi that are less densely populated or less exposed to flooding. Secondly the seemingly secondary priority of manure reuse implies that people may not be as concerned about the safe management of the composting process and simply want something hygienic that does not collapse. This was mentioned by two users who did not reuse compost:

"So from 2008 we harvest once a year but we just throw it and pile it at the back"
(Ecosan User, Project 5, Female, 23)

This issue could perhaps be improved if there was a greater understanding of the market potential and demand for the compost so people would be able to sell compost rather than disposing it.

5.5.5.3 Social Capital

The issue of legacies of previous projects in Mzuzu was identified in point 6 of Table 5-2. Though there are no projects currently implementing Skyloos in Mzuzu, the legacy of the different projects may make it difficult for other projects to implement Skyloos again. This is particularly prominent with project 4 where the project was stopped before many toilets were completed and people said they could no longer find the business. This is despite the organisation still being active on sanitation projects in the city:

*"The organisation came to me with the Skyloo idea. They came here through the council as in this area toilets are often waterlogged. They came with the council and mzuzu university so I was expecting you would come to see me some time. The council owns this land. So we were told we should bring sand and bricks and then get a loan of MK25,000 (*USD*34.49). We were told we should be in groups and have an account for managing. Then they took the money and vanished but I'd already finished the loan and the toilet."*

(Ecosan User, Project 4, Male, 71)

*"I have a farm in Nkhorongo where I'd like to use but when I looked the papers they gave me said I had a loan of MK200,000 (*USD*275.91) but only got MK70,000 (*USD*96.57) from the bank. I got bricks and cement and started building. Then people from the head office in Blantyre came to me and said that they'd had many complaints about people not getting correct amount and they advised me to stop building while they investigated."*
(Person with uncompleted ecosan, Project 4, Female, 35)

*"We got MK100,000 (*USD*137.95) from bank that would go straight to them but then they just took the money but for me it was still being deducted"*
(Ecosan User, Project 4, Female, 54)

This presented issues for conducting the research, as the researchers were often perceived to be part of the project that had left with their money particularly at the start where we had been referred by a member of the organisation. One interviewee asked why it had taken so long to come and see her as the project knew her, though the snowball sampling had only found out about this project the same day as the interview. This was often an issue with many interviews where the research was associated with other previous projects which would leave a legacy for anybody trying to implement Skyloos on similar models to projects that have already been implemented and left a reputation.

5.5.5.4 Landlord Tenant Relationship

The management of sanitation facilities between landlords and tenants is a challenge to the proper operation of Skyloos in Mzuzu, as identified in point 4 of Table 5-2. This often leaves tenants using pit latrines with the same design problems that drove the implementation of Skyloos in the city. Many (20/47) Skyloo users in Mzuzu mentioned issues with ensuring proper maintenance between the landlords and the tenants, with 7 interviewees building a pit latrine for tenants to use instead. The issue of religion was cited by two landlords using Skyloos from project 5, where the common Muslim practice of washing with water instead of wiping can affect the composting process if water is added to the pits. One interviewee kicked out his tenants due to the issue and replaced them with different tenants whilst another also mentioned it as a difficulty of management:

“religion can be an issue as some wash with water but just need to make sure that they all know and they can do it somewhere else. The use of ash is also sometimes a challenge but mainly it is that of water.”
(Ecosan User, Project 4, Female, 53)

Another issue in the landlord tenant relationship was that of users not using Skyloo toilets properly, in different ways:

“There are some issues particularly with the tenant as sometimes he can be drunk so I’ll have to go and apply ash after he has been.”
(Ecosan User, Project 3, Female, 30)

A prominent issue that could develop more in the future was that of tenants moving in to houses with Skyloos already installed. This was particularly prominent with project 2, where 6 out of 8 interviewees had moved into the houses as tenants and often knew less about the management of the Skyloo as they were relying on neighbours:

“*I heard from my neighbours the need to use ash and sand but not from the landlord as I haven’t communicated with him. There is also no hole for urine diversion here.”*
(Ecosan User, Project 2, Female, 20)

“I got to know about ecosan from my home in Rumphi where the extension workers shared the idea with me. So when I moved here I already knew about the technology but didn’t communicate with landlord only by phone”
(Ecosan User, Project 2, Female, 30)

The risk of this issue is that if people move from houses with Skyloos installed fairly regularly then other people move in who are not particularly accustomed to the idea and may mismanage or simply build a pit latrine in the long run. Looking at the potential for Skyloos in Mzuzu as a source of improved sanitation and reuse, the landlord and tenant dynamics in households in areas would need to be understood to assess their sustainability.

5.5.6 Direct Re-Use of Faecal Sludge

The issue of farmers re-using sludge around the treatment plant before it was treated due to the lack of security and enforcement, as identified in points 11, 13, 16, 18 and 19 of Table 5-2.

5.5.6.1 Reuse of Pond material by Farmers

There were two interviewees who did not consent to participating in the research due to the illegal nature of the activity and previous conflict with the government. One respondent, who according to other participants had been arrested and fined MK15,000 (USD20.69) for stealing sludge, consented to participate but said that he had only used the sludge once but stopped using despite being up to date about rehabilitation of the ponds:

Interviewer: *When did you stop?*
Interviewee: *I stopped the same year*
Interviewer: *Would you envisage using in the future?*
Interviewee: *To me I would want to but the rehabilitation means it will be difficult to access from the heavy guarding*
(Farmer Using Sludge, Male, 66)

As well as people who chose not to participate there was suspicion from interviewees which made it difficult to understand at times what the current situation was. In an area where the research found 3 participants we were later told by another that the entire group of around ten people was still using sludge. No common story arose about when they had been able to take sludge and when it had been stopped:

"The time when there were guards there were issues as I think when they saw us coming they thought they could make some money so after if we gave a little money we could access but if we didn't they would say the city council doesn't allow and that it's a disposal site for public health. To some who didn't understand they stopped using it when the guard stopped them but I understood the benefit so I continued to use. Even in the future if I don't apply my land will still be strong."
(Farmer Using Sludge, Female)

"So currently we don't use the sludge ponds as they are restricted and people have been threatened that if they continue they could lose property"
(Farmer Using Sludge, Male, 43)

"No I don't plan to (use). It's not because of the closing as its still in the field of Pit Emptier but I don't want to as I have the (cow) dung."
(Farmer Using Sludge, Female)

The scale of re-use is not clear from the interviews, as often people did not want to refer others to the research meaning the snowball sampling was often limited. It seems there are around 15-20 farmers practicing illegal reuse in the area, and potentially more in surrounding further areas:

"Most farmers in this area, around 100 people are using. Even in Ekwendeni people come here to collect"
(Farmer Using Sludge, Male, 60+)

"I think there are more than 50 but don't want to say."
(Farmer Using Sludge, Female)

What became clear from all the interviewees was a sense of distrust and fear that had built from the arrests and fines that people had been given by guards around the area. Some interviewees had moved to the area more recently and had not experienced this:

Interviewee: *So I came late when moving to this area so I applied when I was planting so I would dig holes in the area and apply it there. I have only just moved here in January*
Interviewer: *Does the Faecal Sludge cost anything to get?*
Interviewee: *We're just getting it free currently*
(Farmer Using Sludge, Female, 66)

An issue mentioned by three interviewees was that of the competitiveness of access to the sludge, which meant that people increasingly rushed to take the sludge:

"So the first challenge is the distance. Secondly because we collect individually there is no communication to share ideas or be able to co-ordinate instead of the way it happens where people simply take"
(Farmer Using Sludge, Female, 30-40)

5.5.6.2 Public Health Risk

The practice of taking raw sludge from the ponds has some clear health risks (Strande, et al., 2014), with children also being responsible for tasks involving faecal sludge in some families, though no interviewee cited health problems. This is different to in Ghana, where 24% of farmers using raw faecal sludge reported health problems (Cofie, et al., 2004). Beyond the farmers using sludge there could be a risk

of food contamination, though only two of the interviewed farmers sold any produce with the rest using food for household consumption:

“To me it’s difficult as mainly I grow vegetables that I sell at hospitals and different areas so my supply contract is with council. So if I’m using the manure it compromises the business.”

(Farmer Using Sludge, Male)

As it is currently managed, the reuse of raw sludge poses large risk to the farmers involved both from the faecal contamination but also the other wastes that can be mixed in:

“The main issues were with the risks of handling as there could be condoms, syringes and other wastes in there.”
(Farmer Using Sludge, Male, 43)

“So there is an issue that when we would go sometimes there would be glass, syringes and other waste. So we would use a hoe instead of hands and then spread it on the ground at our place to remove the waste. We would also use plastic papers for hands sorting.”

(Farmer Using Sludge, Female, 62)

The use of plastic bags for basic gloves was the highest amount of protection cited, and the sorting of glass and syringes suggests risk to the health of the people currently practicing reuse. This combined with the lack of safety equipment that pit emptiers often used highlights the need for improved protection if reuse is to be safe.

5.5.6.3 Issues of Management of Disposal Site

There are a series of issues with the management of the sludge ponds. The first is the balance between cost recovery for maintenance and ensuring that the disposal site is still used by the private sector, identified in points 10, 14 and 17 of Table 5-2. The tariffs currently charged combined with the transport challenges leads to illegal disposal either in other areas or in a nearby field owned by the main septic tank emptier in Mzuzu:

“They will charge MK11,000 (USD15.17) to empty in the future. I will not be paying it, it will be passed on to customer and they can see impact. Our motto is ‘health for

all at low cost' we have to pay dumping, taxes, many costs."
(Septic Tank and Pit Emptier, Male)

*"So we currently charge a tipping fee at MK9,000 (*USD*12.42) per trip and people often do it elsewhere to run away from the charge…. The by-laws in Mzuzu stipulate the fines for illegal disposal of waste in Mzuzu and the fines are not very big. They are controlled by the local government act which prescribes a maximum MK2,000 (*USD*2.75) charge."*
(Mzuzu Council Environmental Health Officer in Sanitation, Male)

Considering that pit emptying services range between MK20,000 (USD27.59) and MK50,000 (USD68.98) per trip, the disposal fees are quite large. Trying to collect tariffs in the future is dependent on enforcement that has previously been insufficient, or building a better relationship with the private sector:

"When they are going to the site it's ok as there is a guard who has a book and records and can ensure they dispose in the right place and that they pay. For elsewhere we try to sensitise the public in the dangers of illegal dumping so often they tell us."
(Mzuzu Council Environmental Health Officer in Sanitation, Male)

"After there were some guards there who didn't stop us either or charge us they simply asked us not to tell the bosses"
(Farmer Using Sludge, Female)

"The time when there were guards there were issues as I think when they saw us coming they thought they could make some money so after if we gave a little money we could access but if we didn't they would say the city council doesn't allow and that it's a disposal site for public health."
(Farmer Using Sludge, Female, 30-40)

One of the issues was the previous design lacked a fence or shelter for a guard to be based which meant that it was easily accessible for farmers to take the sludge when the guard was not around and for the pit emptiers to dispose nearby. When the researcher visited there were children walking barefoot around the site due to the lack of a fence.

5.6 Conclusion on the potential for re-use of faecal sludge in Mzuzu

5.6.1 Opportunities for Increased Faecal Sludge Reuse in Malawi

Our research found the potential for faecal sludge reuse to be expanded. From survey participants a lot of people were found to potentially be open to the reuse of faecal sludge in agriculture. Beyond that there was adoption of Skyloos and compost use, and often users who spoke of there being local buyers who bought compost demonstrating a potential demand for faecal sludge reuse. From the farmers and pit emptiers who also use faecal sludge in agriculture there is a clear understanding that there is a soil fertility benefit, so there is a possible market to sell to if more compost could be produced.

Where the target demographic, landlord-tenant relationship, and openness to the technology were appropriate, the implementation of Skyloos have seen continued use beyond the end of the implementing projects. This requires targeting people who are physically capable of the maintenance requirements, can afford basic tools and time needed and have a clear way of managing the landlord-tenant dynamic. In most cases this would also need sources of finance as well to make Skyloos a viable option for scaling up outside a project. The issue of flooding and constrained space observed in the research area also acted as a driver for people to place increased importance on household sanitation which drives demand for improved solutions with the correct marketing and finance structures.

5.6.2 Constraints to Increased Faecal Sludge Reuse in Malawi

There are constraints to increased faecal sludge reuse in Malawi, whether it is through household Skyloos or centralised composting.

A model based on selling treated sludge from the central site needs an improved working relationship between the local farmers who use sludge directly, feacal sludge management operators and the local government. This will require a management model that prevents sludge being stolen from the site whilst encouraging the private sector to dispose there and recouping enough money to fund maintenance. This involves a balance of enforcement and tariffs that can keep the service functional. A key component to this would be getting a clearer understanding of the value of compost, as currently it is a fragmented market with varying valuations and application. A clear understanding of the potential revenues from increased collection and compost production would help to plan management

models that can get the balance right to increase waste collection for increased compost production.

To improve household sanitation there needs to be increased marketing and finance sources. Improved sanitation being sold up-front is not going to be financially viable for sections of the population in urban areas which have seen several donor projects, some with varying problems, though different Skyloo projects demonstrated the ability of people to pay in instalments over longer periods. The study by Chunga et al. (2016) concluded that the benefits of permanence and fertiliser did not outweigh these issues, so it may only be perceived as beneficial when the driver of high groundwater is prominent as it was in this particular research case. It may also be that Skyloos are only suited to a small segment of the population, showing the need for a greater promotion of different options. All the projects except project 1 implemented Skyloos as a single-choice technology for sanitation, which may have led to some of the issues emerging when households may have chosen other options if provided with information and choice combined with financial access.

Both approaches to reuse currently fail to serve the most vulnerable members of the population, suggesting that for ensuring basic levels of sanitation to be achieved with the poorest the emphasis should be on ease of access rather than reuse due to the physical requirements. Previous research in Malawi has also found WASH programming to be limited in reaching disabled people which inhibits the ability to achieving WASH access for all (Chirwa, et al., 2017; Chunga, et al., 2016)

5.6.3 Applicability of Agent-Based Modelling

Due to the data collected looking at the human elements that lead to success or failure of faecal sludge treatment and re-use ABM is considered a suitable approach for looking at the success of socio-technical systems for faecal sludge re-use. This is explored in section 7.

5.6.4 Overall potential for re-use

There is the potential for faecal sludge reuse in urban areas of Malawi to be expanded, with demand existing for agricultural application of faecal sludge. Producing compost from the treatment site needs a new management model to end illegal collection and balancing the needs of stakeholders: septic tank and pit emptiers, farmers using faecal sludge and the local government. The existing state

of pit latrines, particularly in informal areas, highlights the need for improved household solutions which would require increased marketing and access to finance. Skyloos have been shown to be used long term in cases when they are introduced correctly by projects. But they have not naturally scaled up, and they are unlikely to be a solution for major sections of the population due to the need for direct marketing, maintenance requirements, social acceptability and expense. A wider array of options need to be promoted throughout the city to allow people to choose suitable technology that can eventually lead to safe reuse of faecal sludge.

5.7 Reflexivity

5.7.1 Constructivism vs positivism

The relationship between me and my research assistant in Ghana and Malawi was highly influential on the process. One aspect that I think has arisen is the fact that often the Universities conducted positivist social research that mostly centred on surveys. Combined with the fact that whilst I have spent 2 years of my PhD getting a grounding in constructivist issues and thought, my training and background is still in science and positivism. At times this seemed to lead the research more along positivistic lines and extractive nature. This was quite different between Sunyani and Mzuzu though where people had varying experience of doing this sort of research. One example when discussing with a colleague was that they said they would prefer to do lab studies sometimes because trying to do the work in practice ends up with it not working out, whereas arguably that line between the theory and actual realisation should surely be the focus rather than continuing to improve theoretical studies. This clash was also observable in Ghana where a colleague was often looking to conduct interviews in a more structured manner of a survey whereas I was trying to keep the interviews open. This is also a difficult format to achieve in interviews with a translator though due to the three-way interactions.

5.7.2 Access and Acceptance

An issue that was more prominent with the research in Mzuzu was that of getting acceptance and consent of interviewees. This was particularly prominent in the relationships around illegal disposal and re-use of faecal sludge by farmers. With people having previously been arrested or fined for taking sludge from the disposal site in Mzuzu they were very distrustful of me and the research when we went. It took 4 separate visits after being referenced by snowball sampling to the area to be able to meet with a leader of the group. A lot of the interview would bounce back

and forth with certain questions leading to her asking why we were interested in these questions, beyond this distrust they then often wanted to know what the benefit would be and there was little to offer them on this front. This unease raises the question of how honest interviewees were willing to be when answering questions and particularly emphasises the need for longer term relationships to be built when there are issues of illegality and government conflicts to be explored.

5.7.3 Expectation of Research Team and Participants

One development that improved the process of research from the Sunyani case study to Mzuzu was building a clearer relationship and expectations with both interviewees and research participants. This mainly draws from improved communication and preparation when conducting the research. Firstly when working with researchers from Mzuzu University I was able to have a longer time to build a relationship with them, explain the purpose of the research and their role. It was also significant that they had more experience conducting qualitative research about water and sanitation than in my previous research. For this reason they were more accustomed to the need to give me a full translation, and that the role was to gather opinions. This also fed into a better relationship with interviewees where due to previous experience of knowing that participants may expect something from the research or wonder what its purpose is, we spent longer explaining the need to collect the information to advise for future projects. Overall these two aspects seemed to lead to less confusion with interviewees and people were clearer about why they were being asked to participate. The other possible explanation could be that due to the research targeting adopters of Skyloos they were more used to being interviewed as they had been interviewed for the previous NGO projects before implementation. This could mean they were more prepared to be asked about sanitation than in the Mzuzu case study where people were being asked about their sanitation situation and were less clear why. The other possible explanation for people being more understanding of the research purpose in Mzuzu could be due to the fact that household sanitation is more of a problem there with flooding and collapsing latrines. Sanitation was basically functional for households in Sunyani and the main environmental problem was out of sight at the treatment plant, which may mean that people were not as used to being interviewed about the topic.

5.7.4 Perceptions of Researcher

One aspect that arose more in the research in Mzuzu was being tarred with the brush of previous researchers who had spent time in Mzuzu. There seems to have been more researchers spending time in the city than was the case in Sunyani, particularly when looking at Skyloo adopters who had usually been found through an NGO project. Often when I would introduce myself or the research interviewees would make connections between me and either previous projects or other research that had been done in different departments or different universities that I had not previously been aware of. When talking to one interviewee who had adopted a Skyloo from project 4 who we had found from snowball sampling from the person who was running the project, the interviewee was asking why it had taken so long and was annoyed as her toilet had been left uncompleted so when we said we were associated with this person the interviewee perceived us as part of the business that had taken her money. Whilst we tried to explain the situation I think once the perception of us being related to the other side and with the business that had done wrong by her it was hard to build a relationship. This can be seen as another symptom of the problem of short-term research where little links are made and often it is difficult to then follow up and present back so when the next person comes along they get more and more frustrated with the researcher. When visiting another house where Skyloos had been installed but with some local frustration we were again perceived as part of the project, and spent time with the interviewee discussing many of their issues. These ranged from annoyance that as part of the development project a plot had been taken from someone, to the price of water and lack of rubbish collection (which they mentioned as our introduction said we came from the centre of water and sanitation). The interviewee also complained that their Skyloo had been used as a demonstration site and people were often being shown around their house. This again created a barrier between the researcher and the participant. A lot of these problems partly stem from the methodology adopted by the researcher that allowed for minimal time to be able to build links with research participants and instead still had the perception of a brief visiting foreigner, not dissimilar to other previous projects, leading to my research being grouped with other people in the past who had come and gone. This is partly a concern in terms of how open and honest participants were with me but on a grander scale it seems to be symptomatic of a culture of people who are doing development to others and leaving this schism between us. This issue can be seen in projects like the Skyloo

where the trust is suddenly eroded and it is very hard to build back and hard to break the assumption that we are the same group. It's hard to argue that my research has broken the trend significantly either, as I have yet to be able to present any findings back to participants or to explain what has emerged from the work. Whilst I may be able to write papers for publication it is highly unlikely that this a form of communication that will be suited to the research participants so I have probably been added to the list of people who came and asked questions an disappeared which may make it more complicated again in the future to try and achieve engagement in projects like the Skyloo project.

5.7.5 Grounded Theory or Action Research

In cities such as Mzuzu and Sunyani, where the existing literature is fairly limited and there is not a huge NGO presence, an approach closer to grounded theory would be more suitable to investigating research questions. There may still be a reasonable amount of data and information that can be collected before. More targeted use of internet and communication may enable improved understanding of the research context before starting fieldwork, at least in getting a basic view of the infrastructure. In terms of sanitation, Susana provides a forum for discussions which may enable a researcher to pursue a topic from a geographically specific approach rather than according to a narrow topic in a broad geography (susana, 2018). It also provides an opportunity for initial networking with stakeholders which may help to gain information and build relationships plan before going to the field. Having a flexible research plan in terms of research aims will require adaptability from the research team, but on a positive side it allows the research to follow the local situation rather than trying to control the research from a different continent. This would allow the researcher to spend more time learning local languages which allow for much more integration into a research community and for more ethnographic methods to be used rather than the constructed scenarios that were common to this research.

If the research were to be in cities such as Kumasi, cities with more academic, NGO and economic activities, then a more action research approach would be suggested to utilise limited resources. This would allow the research to be integrated into a longer term network of practitioners who remain in the city. It would also allow the research to build upon existing knowledge and advice on projects that are actually being applied.

5.7.6 Prioritise Language, Time and Observation

If the research were to be repeated again, the project would be planned so as to maximise language learning, fieldwork time and observation. This may require reducing the amount of contexts that are investigated in order to understand a place in better detail.

Language learning and reducing dependence on translators would enable the research to move beyond the form of a foreign entity entering communities and constructing situations in which the topic is narrowly defined along the research objectives. The inability to simply spend time with research participants or move beyond basic conversations, or only speaking to people who are educated enough to speak English fluently enough to discuss aspects, held back the research in many ways. The other aspect of learning languages would be the ability to actually build better social ties, which means there would be less of an isolation aspect to how long the researcher can spend conducting fieldwork. The sense of social isolation experienced in fieldwork often led to me cutting myself off from people which contributed both to personal difficulties in conducting research but also exacerbated the perception of me as a foreigner who does not want to integrate with communities. People would often speak of white people, and particularly British people in Mzuzu and Sunyani, who did not talk and simply hid away. I have to acknowledge that my lack of language and personality probably exacerbated this perception which not only hindered by research process but could hinder future researchers.

5.7.7 Agent-Based Modelling

A further development in research beyond adapting methods and approaches for future research is to look into the potential of ABM to answer research questions. Instead of simply modelling economic and technical aspects to assess whether a biogas system or composting system could be successful in the case studies, the agent-based system allows to model interactions and relationships beyond economics. This could possibly demonstrate a system where technical models can be assessed within the social context they are operating and how government and private sector relationships would affect success of different models. This could possibly provide a forum in which the importance of aspects like government relationships can be integrated into forecasts for technological systems as well.

Section 7 will explore the potential of ABM in modelling re-use systems in Sunyani and Mzuzu.

6 Comparison of Case Studies

This section presents the major differences between Mzuzu and Sunyani case study findings, particularly with regard to the technical systems which leads to an increased suitability of biogas for Sunyani compared to Mzuzu and the political relationships that make a better environment for management of such systems in Sunyani as compared with Mzuzu. The issues are summarised in Table 6-1.

Stage of FSM Chain	Case in Sunyani	Case in Mzuzu
Household Sanitation	1. Large amount of population served by public toilets that can be accessed for emptying	2. Majority of population served by pit latrines which collapse and flood and are inaccessible
Collection	3. Improved road network allows access for trucking companies to empty facilities but road to treatment site difficult to access	4. Poor roads that often cannot reach many households to empty latrines and road to treatment site is poor
Transport	5. Less reports of private sector disposing illegally to avoid using treatment site, possibly due to low tariffs	6. Sludge is often disposed illegally in different areas
Treatment	7. Treatment site fails due to lack of funding and regulation	9. Treatment site fails due to lack of funding and regulation

	8. Level of co-operation between private sector and government	10. Management often fails due to conflict between private sector and government
Reuse	11. Combination of receiving organic solid waste and public toilet waste improves viability of biogas	12. Proximity of agricultural end-users of waste improves possibility of re-use in agriculture

Table 6-1: Comparison of Sunyani and Mzuzu

6.1 Technical Aspects of Sanitation

6.1.1 Public Toilet Network

The major technical difference in sanitation services in Mzuzu and Sunyani centres on the presence of public toilets in Sunyani, as referred to in points 1 and 2 of Table 6-1. These serve poorer segments of the population meaning that a higher amount of the urban population (69%) uses either septic tanks or public toilets that are easier to empty than pit latrines. Public toilets also provide a centralised collection point that vacuum trucks are able to access for emptying services whereas private facilities are more difficult to reach due to the road network. This difference in infrastructure contributes to more waste being collected and disposed by the private sector in Sunyani than in Mzuzu where most households still do not use emptying services. The regular collection and emptying of sludge from public toilets means the sludge collected in Sunyani is more suited to biogas production. In Accra sludge from public toilets had a five times higher concentration of total volatile solids than normal septic tank sludge (Kone & Strauss, 2004) indicating much higher viability of sludge for anaerobic digestion than from private toilets (Sosonowski, et al., 2003). The increased biogas potential production per unit of sludge collected means that there can be more biogas produced from a digester of the same size increasing profit margins.

6.1.2 Road Network

The road network in Sunyani was more stable and accessible than in Mzuzu for transport services as identified in points 3 and 4 of Table 6-1. During data collection

in Mzuzu there were often times where heavy rains would make roads either unpassable or very slow except for the main roads. In Sunyani more of the roads used by transport companies and by the researcher were tarmacked with better drainage systems meaning more of the road network was consistently accessible in rains. There is still an issue in Sunyani when trying to access the treatment plant as the road is not tarmacked there and in heavy rains can become difficult to use for trucks that are heavily loaded. The road to the treatment site in Mzuzu is also problematic as it is very steep in places as well making access difficult in rainy season.

6.1.3 Existing Sludge Collection

Sunyani has a relatively functioning faecal sludge collection system compared with Mzuzu covered in points 5 and 6 of Table 6-1, which suggests that interventions around treatment and re-use could be implemented on a more centralised basis. The existing constraints that prevent collection, transport and safe disposal of faecal sludge in Mzuzu mean that solutions that are more decentralised could be suited like the use of composting toilets that negate the need for improved transport services. Public toilets could be adapted for a decentralised biogas production model in Sunyani, though this would still require complex processes if it was intended for bottling and selling for cooking. There would also be the more explicit link between the toilets and the end product if it was being sold in the same place which may make people less inclined to use biogas. If there was a clear function for small amounts of electricity at public toilets they could perhaps be adapted for charging mobile phones or other functions.

6.1.4 Combined Collection of Sludge and Solid Waste

In Sunyani the disposal site receives faecal sludge and solid waste, whilst in Mzuzu the two sites are separate and a few kilometres away from eachother as identified in point 11 of Table 6-1. The main implication of this is the ability for re-use models to be designed for organic solid waste as well, either in co-composting or biogas production. This could increase the value of products generated for re-use, whilst also potentially reducing the issue of solid waste which is prominent in both cities. The value of solid waste in Sunyani for biogas production is unclear but the combined use of organic waste and faecal sludge can result in higher yields.

6.1.5 Proximity of Sites for Re-Use

Due to the increased prominence of agriculture as an economic activity in Mzuzu, the transport distances to farms that could re-use compost are reduced compared to Sunyani as identified in point 12 of Table 6-1. In Sunyani there were areas outside of the city that were involved in farming who came to the city to buy compost for transport. The decreased nutrient content of compost per kg compared to chemical fertilisers means that the difficulty of transporting a comparable amount of FS-based compost would be increased in Sunyani. Whilst transport of compost was also an issue cited by interviewees in Mzuzu, the distances are often smaller and when people are applying compost from Skyloos they often have small gardens or patches of land nearby that are used for growing maize in small quantities.

6.2 Social Aspects of Sanitation

6.2.1 Government-Private Sector Relationship

As well as the major differences in the sanitation infrastructure and its suitability for different technical options for re-use, there are also contrasting political environments and relationships around sanitation in Mzuzu and Sunyani as identified in point 8 and 10 of Table 6-1. One of the major differences is the way the relationship is perceived, with Sunyani local government slowly seeming to withdraw from providing vacuum truck services and seeing theirselves as less of a competitor:

We asked private companies to come in to reduce problems with transport so there are no problems.
(Stakeholder interviewee, waste management department local government)

Often with the beauraucracy it makes it difficult here. They have to come here, make a request, pay, take the receipt and then wait for us to empty whereas companies can empty straight out in one call. Even though we only charge 110 cedi and they charge 150 cedi.
(Public toilet owner, male)

In Mzuzu, though, the local government still sees itself as service providers in the area and competitors for the private sector:

With the entrepreneurs they are profiteers and they could just send prices higher and higher so we try to balance them out by offering our pricing. We are also responsible to making sure the ponds are looked after and that they deposit

properly. So we currently charge a tipping fee at MK9,000 (USD12.42) per trip and people often do it elsewhere to run away from the charge.
(Stakeholder interviewee, waste management department local government)

The role of competitor and regulator that the local government has in Mzuzu seems to affect the relationship with the private sector. Entrepreneurs claimed that the dumping fee charged, not paid by government trucks, allows for them to be undercut in price and loses customers. The main business was also looking to pursue composting and reuse their self rather than having to use the government treatment plant leading to another source of competition and conflict, which has implications for future operation of the site. There are other aspects to the relationship and conflict that are increasingly complicated, with suggestions that the providers have links to the national government which affects the power relationship again between them and regulators as they are able to bypass them. These relationships were too opaque to be understood in the time of the research, though it can be simply stated that they work against each other currently. These opaque political relationships seem to be more prominent in Sunyani around the more profitable service of public toilet operating contracts. This was covered looking at Kumasi and in rural Ghana (Caplan, 2010; Ayee & Crook, 2003), with interviews with owners and operators suggesting that similar dynamics in Sunyani. This remains less of an issue than the dysfunctional relationship around transport in Mzuzu, as public toilets are still regularly emptied for collection even if their hygiene is questionable, whilst the private sector environment for transport in Mzuzu leads to a lot of sludge being dumped illegally and not treated.

7 Agent-Based Modelling

7.1 Section Structure

This section explores the use of ABM as for simulating potential sanitation systems and management approaches to reuse of faecal sludge in Mzuzu. Sunyani was not explored due to the nature of the data collected which was limited in terms of 'agency' around the management of the treatment plant and the profitability of biogas production. Instead the economic modelling of potential business plans is considered the best exploration of the data collected, which could be improved with both technical data of sludge quality from public toilets and observation data from the biogas plant in Accra to inform modelling of decision processes around biogas operation and maintenance. ABM is explored for looking at both how Skyloos and safe reuse of sludge could be expanded in Mzuzu.

7.2 Modelling Framework for Mzuzu

Having identified two forms of reuse being practiced in Mzuzu, two separate ABM are developed for the systems in Mzuzu. This is based upon the fact that most interviewees who adopted Skyloos were previously using pit latrines that were not disposed at the central treatment plant so the two forms of re-use are limited in their connection. Separating the two forms of re-use allows them to be looked at over different timescales or in more or less detail while only changing parameters that affect each form of re-use and using less computing power.

7.3 Adoption of Skyloos

7.3.1 Modelling Framework

Having collected data around the success of projects implementing Skyloos at household level in Mzuzu and the level of adoption and continued use, ABM could potentially provide an opportunity to forecast the potential of Skyloos if they were to be implemented as a project again in Mzuzu. This model would follow on an 'innovation of diffusion' structure where ideas are introduced to social networks of people in Mzuzu, and then the technology is or is not adopted and the idea can spread amongst the community.

The following questions are listed below to observe ways in which ABM could further understanding of the potential for Skyloos to be a sustainable option for household sanitation in Mzuzu:

1) What is the potential scope of a project implementing Skyloos in Mzuzu in terms of number of customers that can be reached?
2) What effect does network structure and links have on diffusion of innovations and products?
3) How much would the marketing approaches of a project implementing Skyloos affect the success of implementation?
4) What level of investment in marketing would optimise success of a Skyloo project?
5) How economically viable would different approaches to implementing Skyloos in Mzuzu be?

The diffusion of Skyloos can be seen as a similar problem of a network diffusion of technologies along a social network, as was explored in the context of East Germany (Panebianco & Pahl-Wostl, 2006). People had either been introduced to the technology by close family members or friends or by an implementing organisation. The model will explore the potential for Skyloos to be implemented as a business in a similar approach to project 3 in Mzuzu, shown in Table 5-1, rather than a subsidised approach to explore whether cost recovery and profit can be achieved. The model can be broken down in to a list of environmental factors, agents and potential interactions and actions that can be taken as shown below in Figure 7-1.

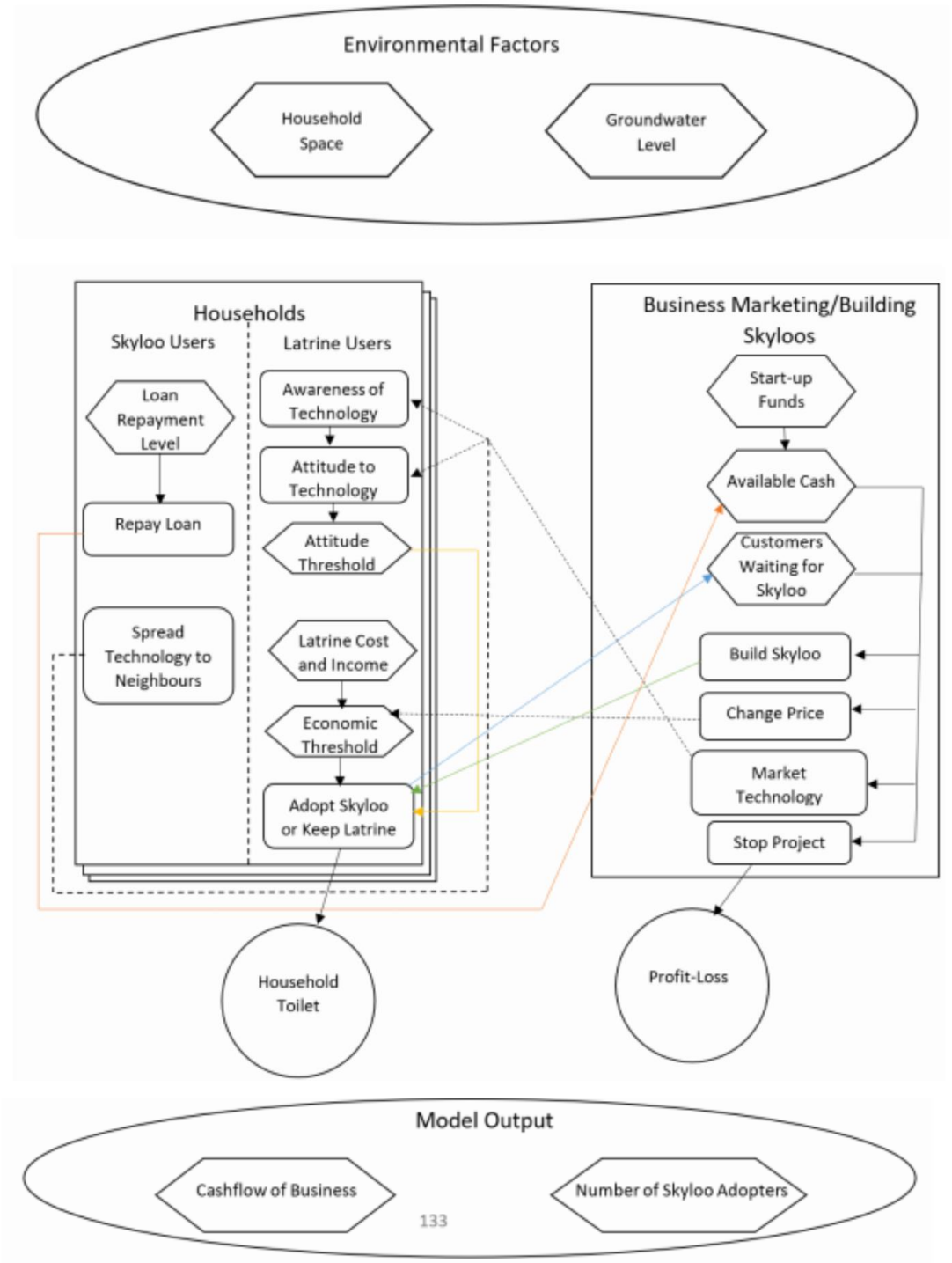

Figure 7-1: Model structure for Skyloo adoption

7.3.1.1 Interaction Set-Up

Modelling Steps	Assumptions	Justification
Set up households	1. 3,026 households set up from research areas. 2. Set-up in spatial network. 3. 50% owners and 50% tenants. 4. Household size distribution mean 6 standard deviation 2 5. 0.3% probability of already having Skyloo. 6. Household monthly income distribution mean MK44,000 standard deviation MK44,000, income below MK5,000 set to MK5,000 to avoid 0 or negative values. 7.64/148 probability of household being open to re-use in agriculture but do not know where to access. 64/148 probability of being against re-use in agriculture. 20/148 probability of not knowing about re-use.	1. Reasonable sample size but able to model. 2. Can model space and flooding issues. 3.(Mzuzu City Council, 2011). 4.Survey data found mean household size of 5.44 and standard deviation 2.3. Integer values used. 5. 0.3% of households adopted based on estimate of 100 Skyloos in city. 6.Survey data found monthly household income mean MK43,500, standard deviation MK43,700. 7. 64/148 interviewees were open to re-use in agriculture but did not know where to get a Skyloo so would need marketing or social network interactions, 64/148 were against it due to hygiene or other issues and 20/148 only were against reuse due to lack of knowledge.
Set up business agent	1. Start-up fund of MK2million or MK10million. 2. Building capacity of 1 Skyloo per day.	1.Changed to observe effect of start-up fund. 2. Interviews said building took around a day and one trained builder at business 4.

	3. Modelled as business 3 from research (Table 5-1).	3. Most successful organisation and used loan-based cost recovery model
Link households in network	1. Small-world network structure used. 2. Houses linked to 4 neighbours in ideal network then rewired at probability of 0.2.	1. Can model social networks in a relatively simple method (Bohlmann, et al., 2010; Watts & Strogatz, 1998). 2. Gives clustering and connected social network representation.
Set up probability of gaining knowledge and becoming open to reuse for households	1.Initial probabilities of 100% for marketing and 5% for knowledge spread from business and linked neighbour respectively. 2. Initial probabilities of 25% for marketing and 3% for spreading openness to Skyloos from business and linked neighbour respectively. 3. Multiplier of 0.8 applied to probabilities for households with tenants 4. Multiplier of 1 – (land area/ largest area) applied to probabilities 5. Multiplier of 1 – (distance to river/ largest distance to river) applied to probabilities	1. Represents that if marketing reaches households they will then know about the technology, whilst small chance that neighbours will spread technology in interaction. 2. Lack of data around adoption process except that marketing was more successful (section 5.5.4.1 and 5.5.4.3). 3.Represents decreased probability of investment in sanitation from renters (section 5.5.5.4). Lack of data to introduce improved agency. 4. Smaller households more likely to run out of space for latrines and want to adopt permanent Skyloos (section 5.5.5.2). 5. Houses closer to rivers/dambo areas more likely to flood and want raised Skyloos.
Business conducts initial	1. Reaches 300 households 2. Does not market to households that are against technology due to hygiene	1. Assumption of amount of people that can be reached based on photos shown by projects and

marketing of Skyloos		interviews with people who conducted marketing before 2. Workshops and marketing requires some engagement in the technology so those who are completely against it unlikely to be open to marketing
Households become aware of/open to Skyloo technology	1. Households awareness set to 1 (passing awareness threshold in Figure 7-1) 2. Random number used for probabilistic function, if random number below 10000 < probability * 100 then household openness set to 1 (passing openness threshold in Figure 7-1)	1. Marketing is successful at spreading awareness to households 2. Random number generator allows percentage probabilities to be used. 10,000 used and probability * 100 to give integer representations e.g. if chance is 4.36% after multipliers random numbers below 436 will spread openness for household.

Table 7-1: Modelling setup of ABM for Skyloo adoption

7.3.1.1.1 Network Structure

Due to the importance of flooding and space in adoption of sanitation facilities, the use of spatial data in modelling household networks is important to present a more realistic adoption process. In the research fieldwork it was not possible to collect spatial data in terms of land ownership and space for households, or the groundwater levels in urban areas so proxy measures were used based on qualitative data collected and open source spatial data available from OpenStreetMap. OpenStreetMap has open source files of road networks, water bodies and building areas available for Mzuzu. Firstly land areas were calculated around buildings using thiessen polygons in GIS, as shown in Figure 7-2. Land areas were calculated based on the area of the thiessen polygons minus the area of the building to calculate available space. As house areas and how the land is used for latrines was difficult data to collect, probabilistic measure of willingness to adopt based on land space was calculated as 1 – (area/largest area in dataset) so the smallest house would be close to 1 and the largest would be 0. This represents the space driver of preferring Skyloos over digging latrines in new areas regularly. A

similar function was used to measure the flood vulnerability of houses by proximity to water-bodies, with 1 representing the houses closest to water bodies and 0 those furthest away. The area studied focused on houses in Chiputula, Chibavi and Zolozolo to minimise the requirements for spatial data usage whilst providing a large population for modelling and using the areas that were studied in both surveys and interviews. Houses are set to be 50% owners and 50% tenants based on Mzuzu city council data (Mzuzu City Council, 2011). Tenants are set to be 80% as likely as owners to adopt technology based on the interviews that showed issues around tenancy adoption. As data with non-adopters was not collected, this is a simplistic assertion made simply to explore the fact that ABM can simulate and account for the difference between owners and tenants. With more data this could be replaced with a calibrated probability to reflect the difference, or a more complex behavioural model. The area modelled included 3,026 households, which at the average household size of 6 from household surveys, shown in Table 7-1, represents around 18,000 people.

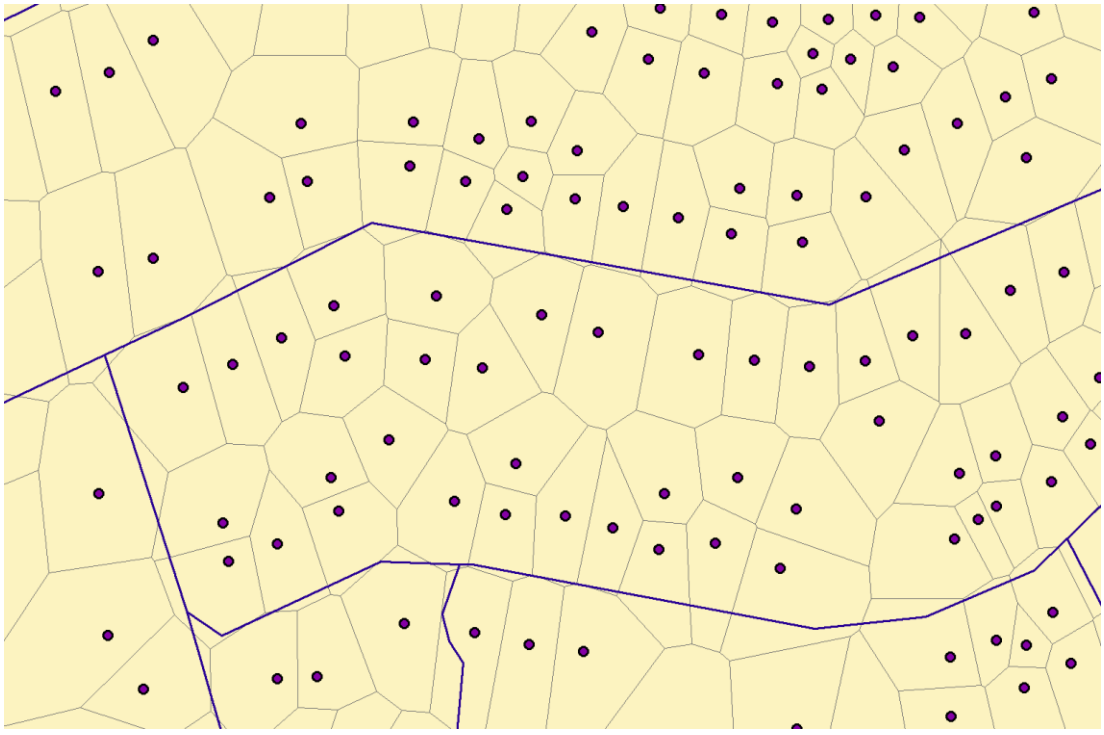

Figure 7-2: Section of Thiessen Polygons from GIS Mzuzu data Source: Map Data: © OpenStreetMap contributors

Households are linked along a network to simulate a social network along which innovations and ideas can be spread. Households are linked along a Watts and Strogatz (1998) small-world network structure as described in previous ABM

literature (Laciana & Oteiza-Aguirre, 2014; Bohlmann, et al., 2010) and shown in Figure 7-3. Small-world networks are used to model social networks by initially linking all neighbours in a perfect lattice, for example linking households to their neighbours. After this each link is rewired with a probability between 0 and 1, creating clusters of interlinked neighbours whilst also having a small distance of links between any two sets of neighbours. This models the social environment as a small-world where any two nodes are linked by a short amount of neighbours, as would be expected in local communities being simulated in Mzuzu, whilst having the local clustering of groups that were observed in savings groups with project 4. An open source Netlogo code for small-networks is adapted for use in this model (Wilensky, 2005). Houses are linked with four neighbours and links are rewired with a probability of 0.2 to create a small world with clustering and low distance between agents. With further data collection around the structures of social networks in Mzuzu this initial modelling assumption could be improved.

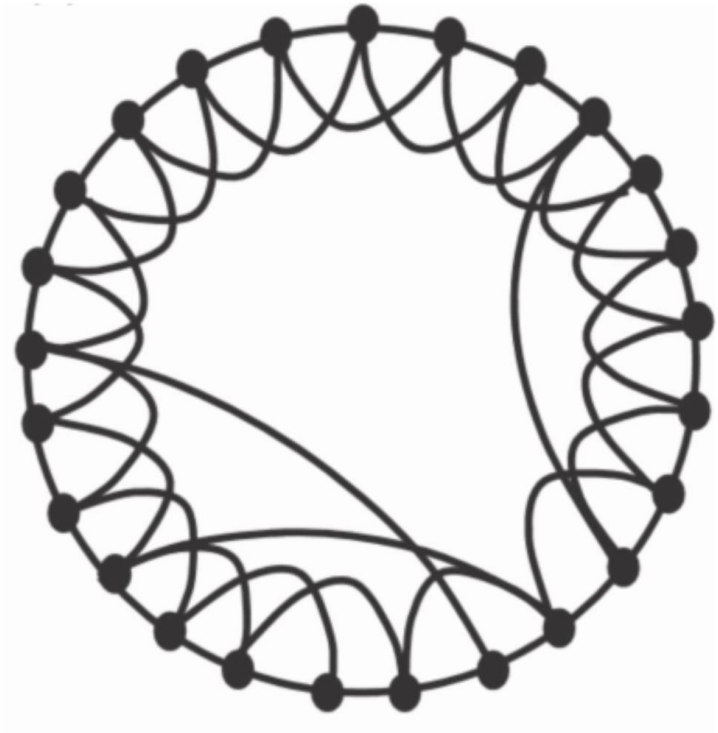

Figure 7-3: Small-world network (Bohlmann, et al., 2010)

7.3.1.1.2 Initial Adoption and Marketing

The model is seeded with initial adopters of Skyloo toilets based on the fact that there are currently users of the technology in Mzuzu from previous projects and that any further project would be starting with this base level. Based on the fact that

there are estimated to be around 100 Skyloo-using households as a whole from interviews with the different organisations and a population of 200,000 equivalent to 33,000 houses an initial adoption rate of 0.3% of households is used in the model. In the initial set-up of the model households have Skyloos as their initial facility with a probability of 0.3% giving varying starting adoption rates of technology across different model runs.

An initial modelling set up has the organisation marketing the technology to 300 random households in the study area, reflecting the initial large-scale marketing approaches taken by organisations that previously tried to implement Skyloos. When households are targets for marketing, their knowledge threshold of the technology is set to one, reflecting complete awareness of the technology as the marketing would involve demonstrations, price structuring and maintenance information being given. The marketing is set to have an initial 25% probability of households reaching the openness threshold for adoption, with multipliers applied to households based on land area and flood vulnerability as shown in Table 7-1. There is limited data from the interviews about how successful marketing approaches were, so this probability is used as an estimate to simply explore the possibility of the marketing effects and the agency aspects of the model are instead used to look at the effects of social networks, flooding and land space.

7.3.1.1.3 Network Diffusion of Innovation Probabilities

As well as the marketing of the organisation implementing Skyloos, there is also the possibility for diffusion of technology along social networks. This is modelled using interactions between households along links made in the initial network set up. Households interact with their neighbours and have a probability of spreading awareness and openness to the idea of the technology. The probability of spreading awareness to a neighbour is set at 5% and spreading openness threshold to 3% as shown in Table 7-1. These probabilities are reduced by multiplying the probability by the individual land-space factors and flood vulnerability factors calculated in the network set up. The probabilities are low to reflect the limited spread of technology through networks in Mzuzu and the major driver being marketing.

7.3.1.2 Model Interactions

Modelling Steps	Assumptions	Justification	Model Properties Affected
Skyloo adopters interact with neighbours	1. Households interact with linked neighbours at each step of model 2. Households achieve awareness threshold and openness threshold based on probabilities of 5% and 3% and space and land multiplier	1. Households only have four linked neighbours, so these are close contacts with regular interaction 2. Low probability is used to model the fact that marketing is more successful than network spread (section 5.5.4.1 and 5.5.4.3)	• Awareness threshold of households • Openness threshold of households
Households check adoption thresholds	1. If economic, awareness and openness thresholds are passed households join waiting list		Number of households on waiting list
Business builds Skyloos for customers on waiting lists	1. Requires one day to build a Skyloo. 2. Costs the business MK80,000 for Skyloo materials. 3. MK3,000 deposit paid by household for loan.	1. Interviewees said that it took around a day and there is only one builder at the business. 2. Estimated cost of 5 bags of cement, corrugated sheets	• Number of households on waiting list • Number of households with Skyloo • Cash of business • Debt of households

	4. Loan of MK200,000 made to customers.	of metal, bricks and labour. 3. Interviewees with project 3 households and business 4.Interviewees with project 3 households and business	
Households with Skyloos pay loan	1.Household loans paid at MK9,230 and MK7,000 per month 2. Interest of 1% per month on loan	1. MK9,230 per month is price required to pay back loan (section 5.5.5.1) and MK7,000 per month price is used to model effect of lower payback rate 2. Interviews (section 5.5.5.1)	• Debt of households • Cash of business
Business pays operating costs	1. MK85,000 operating costs for business	1. Initial assumption of wages for three or four staff members for marketing.	Cash of business
Business markets technology to households	1. Businesses conduct marketing if no customers have joined waiting list for a month	1. Whilst new customers are arriving there is no need for marketing. 2. Used as an assumption of reduced scope of	• Awareness threshold of households • Openness threshold of household

	2. Businesses can market to 30 households	marketing after large initial promotion.	

7.3.1.2.1 Economic Threshold of Affordability

Households are set up with distributed income of average MK44,000 (USD60.72) standard deviation MK44,000 based on the income distribution of 148 survey respondents, as shown in Table 7-1.. Households are classed as being able to afford the Skyloo technology if the monthly cost is less than 10% of income, as a simple measure of affordability of technology. This assumption is again simplistic and based on the lack of data around non-adopters of Skyloo toilets. If the economic threshold, awareness threshold and openness threshold for adoption are passed then households become adopters who are willing to build a Skyloo and join a waiting list.

7.3.1.2.2 Adoption and Unadoption

If there are households willing to adopt Skyloos they are on a list of households that the business could build for. If the business has sufficient capital to build a Skyloo for households then they will build the facility and issue the loan to customers with repayments beginning the next month. In some cases people were on waiting lists for Skyloos to be built and have not had them built due to the projects losing finance, as was in the case of project 3 where one loan collector had a waiting list of 11 households who were willing to buy a Skyloo. If households have to wait too long for a Skyloo to be built, they are set to 'un-adopt' the technology after 30 days without the business building a Skyloo for them.

7.3.1.2.3 Marketing of Business

After the initial marketing companies can go to households and market if they have not had any new customers after waiting for a set amount of time. The business conducts more marketing if they have not had new customers for 30 days, and are able to reach 300 people.

7.3.1.2.4 Cost of Business Operation

The business is assumed to have a monthly operating cost of MK85,000 (USD117.30), this is mainly to represent staff costs of hiring three or four staff members, which would be sufficient to market the technology and hire contractors

for building Skyloos when needed. This cost could be higher or lower and would affect the level of finance available for building but MK85,000 (USD117.30) is used for initial modelling of the business plan.

7.3.1.2.5 Cost of Skyloos and Loan Structure

Skyloos are charged at MK200,000 (USD275.91)to customers as an overall loan package based on interviews about the costs of Skyloos. For the business the material costs and cost of hiring staff is set at MK80,000 based on costs of cement and bricks at market and price of contracting staff. Loans are issued for a deposit of MK3,000 as in project 3 and then set at an interest rate of 1% per month. Monthly payments are varied as part of the modelling approach discussed in section 7.3.1.3.

7.3.1.3 Modelling Approach

Having built an initial model of adoption of Skyloos as a business with loans, the model runs are used to explore how price and level of investment finance would affect the success of Skyloos as a business model in Mzuzu. The main constraint to the modelling of Skyloo adoption processes in this case was the time requirements of model runs and the computing requirements for data analysis which led to limited scope for initial modelling. From informal interviews with people who had previously run a Skyloo implementation project in Mzuzu and were looking for funding they were hoping for MK2,000,000 (USD2,760) to start financing. Experiments were run at start-up funds of MK2,000,000 and MK10,000,000 (USD13,800) to see the effect of a large increase in funds on being able to reach larger populations and spread technology faster.

Cost and affordability were also shown to be large barriers to adoption of Skyloos. If loans were provided for the full MK200,000 (USD2,759) that is currently charged for building at 1% monthly interest for 2 years then a monthly payment of MK9,230 (USD12.74) is required. As well as this monthly payback of MK 9,230 (USD12.74) a scenario where only MK7,000 (USD9.66) is charged is modelled to see how this effects rate of payback and success of the business.

For both scenarios models were run for 1,000 repeats. This is because of the path dependency of both initial adopters and network success, which can have a large effect on the end results of modelling; for this reason a large number of runs are needed to ensure the results are valid. The model was run for 2,000 steps, with each step equal to a day, partly because this is within the scope of how long any

Skyloo project has previously run. The use of 2,000 steps is also to improve the speed of both the modelling and analysis and processing of data.

7.3.2 Results

Figure 7-4 to Figure 7-7 show the average cashflow, Skyloo adoption and unadoption rate of households in Mzuzu for different start-up funds and monthly charges for 1000 different runs of the ABM model. The cashflows of different scenarios show the importance of having enough initial finance to supply the initial demand that enables the network diffusion of technology to begin as well as the marketing. With the unadoption function of customers not waiting more than 30 days for a Skyloo to be built the importance of access to finance is crucial, as shown with the high number of adopters of the Skyloo technology in the high start up finance, low cost scenario.

Overall, the model results comply fairly well with literature around affordability and diffusion of innovation as to the idea that lower costs aid the diffusion and 'take-off' of products (Golder & Tellis, 1997). This study suggests that the price is the major driver of take-off and adoption of technology, though its focus is on electronics that often reduce sharply in cost over time whereas Skyloos seem to be increasing in costs over time due to increasing material costs. The fact that in the current model, price is a key driver and was shown in interviews to be a key driver of adoption means that future adoption of sanitation technology is not only dependent on the social and human aspects of acceptability but on a greater understanding of ability and willingness to pay and on providing access to finance whilst achieving cost recovery for businesses implementing technology.

The addition of start-up finance into the model also helps to look at the aspect of finance both from the point of view of the households and businesses. Finance availability was an issue regularly cited with business development in sanitation in literature in Sub-Saharan Africa and found in Mzuzu.

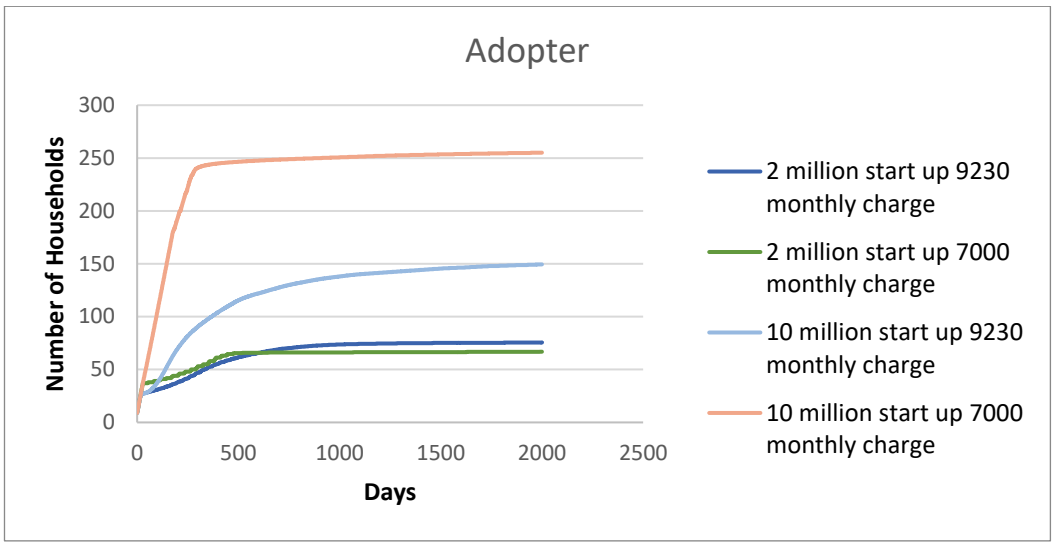

Figure 7-4: Results of ABM showing average adoption of Skyloos over 1,000 model runs based on start up finance and monthly repayment charge

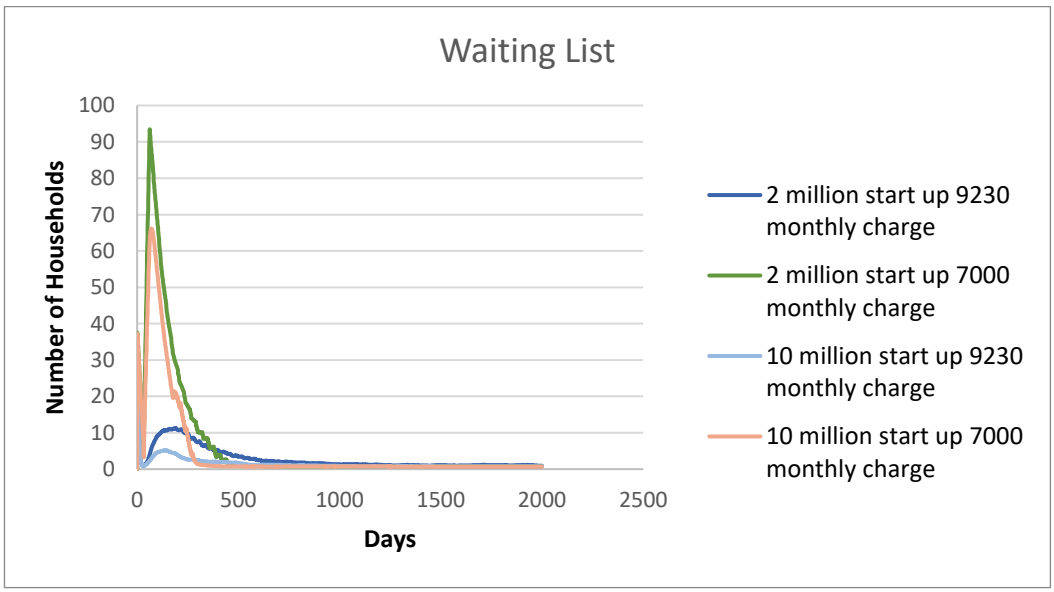

Figure 7-5: Results of ABM showing average waiting list for Skyloos over 1,000 model runs based on start up finance and monthly repayment charge

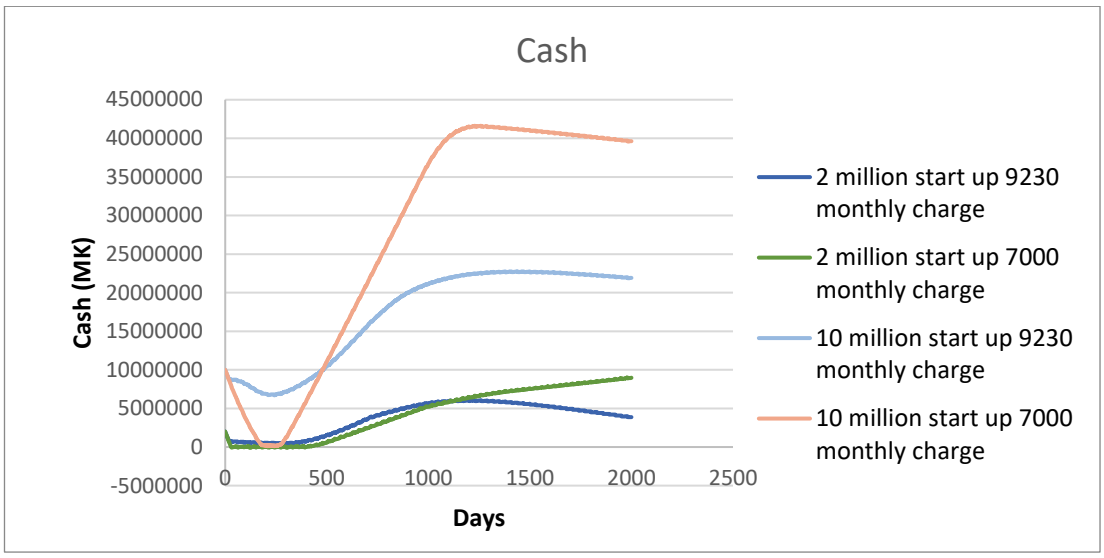

Figure 7-6: Results of ABM showing cashflow of Skyloo business over 1,000 model runs based on start up finance and monthly repayment charge

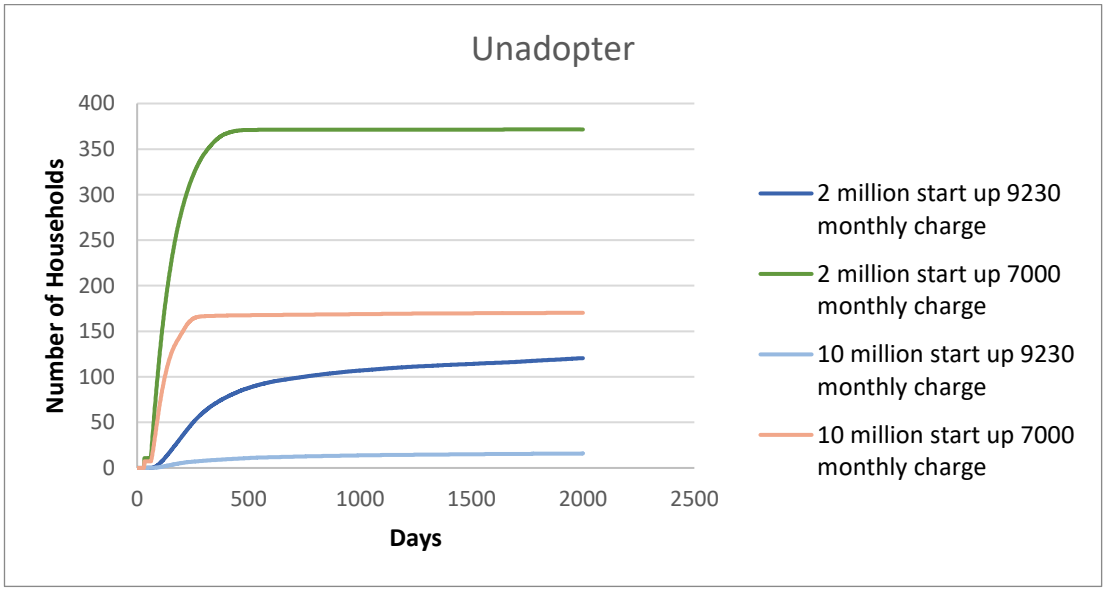

Figure 7-7: Results of ABM showing average number of unadopters of Skyloos over 1,000 model runs based on start up finance and monthly repayment charge

7.4 Interactions around Treatment Plant

7.4.1 Modelling Framework

7.4.1.1 Interaction Set-Up

Having collected data looking at the operation of the treatment site in Mzuzu, the success of the rehabilitated system with a new fence and shelter for the guard is grounded in the interactions between farmers who steal sludge, private sludge

disposal companies who often use on their own land or dispose elsewhere, and the guard at the site. Particularly because there was no activity at the site to observe so as to inform reflections on the new operating model after rehabilitation, ABM offers the opportunity to simulate the previous system and then forecast how successful the rehabilitation could be and look at other solutions that could be implemented.

The main questions to be answered by applying the model to looking at the treatment of faecal sludge in Mzuzu are listed below:

1. What factors influence the interaction between farmers, the private sector and the guard around management of faecal sludge?
2. What effect will the rehabilitation of the ponds with a fence and shelter for the guard have on the operation of the treatment plant?
3. What tariff structures, enforcement strategies and policies could increase the amount of faecal sludge treated and used as compost?
4. How much sludge needs to be collected and treated to fund maintenance?

7.4.1.1.1 Game Theory Approach

Most of the failure of the previous composting system was grounded in the costs of dumping for the private sector, the relative value of sludge to farmers and the private sector and the willingness of guards to either allow disposal/stealing of sludge and to take bribes for it. Without the more detailed information that might be available from long term observation at the treatment plant the model can views the faecal sludge as a valuable product that a series of agents are competing over. This is modelled in a Game Theory system where the decisions to dispose at the site or elsewhere, to enforce the law or take bribes, and to steal the sewage and risk arrest have different pay-offs and consequences.

Game Theory has been used in ABM before to look at how agents adjust their behaviour based on the relative pay-offs of different approaches (Jourgensen, 2018; Wilensky, 2003). Agents have an initial probability of either applying sludge on their own land or disposing, accepting bribes or enforcing the law and stealing sludge or not risking arrest. Based on the effective pay off of each interaction agents then adjust the probability of their behaviour to increase their chances of increasing their payoff in future interactions. For example if the private sector truck goes to the treatment site and pays a tariff to dispose which has a greater cost than the sludge value for use on his own land and a potential fine then he will adjust his behaviour to

increase his likelihood of disposing on his own land. This is a useful system for relatively binary choices taken by agents about whether to dispose legally or illegally, to enforce the law or take bribes, or to steal sludge or avoid fines. The basic first interaction is between the private sector tankers and the guard, as to whether they dispose at the treatment site. In terms of the waste that is collected there, there is then the possibility that farmers in the surrounding area will come and take it depending on if the guard is at the site, and whether he would accept bribes for the sludge. After a 6-month composting period any sludge is assumed to be sold, based on the fact that there was a clear market value identified. This also allows the model to look at the economic potential of treating and selling the waste if the management can be improved.

There are two components to the pay-offs of different behaviours for each agent: the value of the sludge itself if it can be kept by the agent, and the loss/gain of money from paying dumping fees, bribes or fines. The pay-offs and risks of different interactions as a game theory interaction are shown below in Table 7-2 and Table 7-3. For the private sector to apply on his own fine it is assumed that he would have to pay a fine, or would be fined if the guard was present. This is because his farm is located near the treatment plant so it is not possible for him to take sludge to his own farm without the guard seeing it, if he is present at the site.

Guard / Private Sector		There	
	Not There	Bribe	Enforce
Dispose	S.V. / 0	Tariff + S.V. / -Tariff	Tariff + S.V. / -Tariff
Apply on own farm	0 / S.V.	Bribe / S.V - Bribe	Fine / S.V. - Fine

Table 7-2: Payoffs and risks of private tanker interactions with guard for ABM of treatment plant (S.V. = Sludge Value)

Guard / Farmers		There	
	Not There	Bribe	Arrest and Fine
Steal	- S.V. / S.V.	Bribe - S.V. / S.V - Bribe	Fine / - Fine
Don't Steal	0 / 0	0 / 0	0 / 0

Table 7-3: Payoffs and risks of farmers with guard for ABM of treatment plant (S.V. = Sludge Value)

After each interaction, agents adjust their probability depending on the difference between the pay-off of their behaviour and the potential of the alternative approach.

Using Equation 1. The multiplier of 0.000001 was calibrated so that the behaviour within the model changes gradually.

IF payoff < potential payoff set probability of behaviour = previous probability – 0.000001 * (potential payoff – payoff)

IF payoff > potential payoff set probability of behaviour = previous probability + 0.000001 * (potential payoff – payoff)

Equation 1: Probability adjustment equation for Game Theory in ABM

7.4.1.1.2 Number of trips by private sector

As the treatment site was not open at the time of research, it is difficult to estimate the volumes of sludge disposed and emptied by the private sector. Based on the estimates from the private sector and government an average of one trip every day is used with a random volume between 0 and 6,000 litres, the capacity of the trucks used. With further observation data or follow-up interviews with truck operators and government officials after building the model this estimate could be improved.

7.4.1.1.3 Payoff Values

The initial charge by the government of MK9,000 (USD12.42) per trip is used for the model. This is also looked at for a range of MK6,000 12,000 and 15,000 to look at potential effects of other tariffs and sensitivity analysis of the model. As there is record of the private sector and farmers being able to negotiate with the guards (section 5.5.6.3), and also of the private sector being reluctant to use the dumping site due to the price, the tariff structure is the other aspect that can be changed. A monthly license fee is explored instead of a charge per visit from the truck.To simulate the change to a monthly tariff required for licensing, a monthly fee of MK60,000 is used initially, but monthly fees of MK40,000, MK80,000 and MK100,000 are assessed in the sensitivity analysis as well. MK60,000 per month is much lower than the potential revenue of MK9,000 (USD12.42) per day if the law can be fully enforced but reduces the cost of disposing legally to the private sector and removes MK9,000 (USD12.42) fee with which the guard can ‘compete’ by asking for a smaller amount to allow the tankers to dispose on his own farm past the dumping site.

An initial sludge value of MK5,000 (USD6.90) per 50kg bag is used. This is towards the higher estimates of value for which people were able to sell sludge and compost in Mzuzu and runs are also done at values of MK500, MK2,500, MK7,500 and

MK10,000, due to the varying information around sludge value and to assess how much effect sludge value has on the efficacy of the treatment plant.

An initial bribe value of MK3,000 (USD4.14) is used for both farmers and the private sector when interacting with the guard. A value that is lower than the dumping fee and value of large amounts of sludge is used due to the limited data around the guard behaviour and bribes/fines needed. As money that goes directly to the guard is more valuable to him than money going to the assembly from fines or dumping tariffs, a bribe multiplier is used to model the relative value of bribes to the guard. This multiplier is used in the guards decision making process and the payoff of bribes is set to bribe x bribe multiplier. Simulations are run with a multiplier of 1, 2, 4, 6 and 8 to see how the value of bribes relative to money going to the assembly affects the guard interacting with farmers and the private sector. This is a relatively simplistic measure in place of the lack of data and interview with the guards.

The disposal fine is currently limited to MK2,000 (USD2.76) in Mzuzu for illegal disposal of waste due to legislation, whilst the farmer arrested for stealing sludge was fined MK15,000 a few years ago. MK20,000 (USD27.59) is used as the current fine to assume some increase due to inflation. The disposal fine is also explored at MK6,000, MK10,000 and MK15,000 to see the potential effects of a policy of increasing fines.

7.4.1.1.4 Guard Presence/Behaviour

Before the treatment plant was put in for rehabilitation, there were often issues with the guard not being present due to the lack of shelter from either hot weather or heavy rains that are common in Mzuzu. For this reason, in the model simulating the treatment plant before the rehabilitation there is a probability of 65% that the guard is present at the site, this value having been chosen simply to show the fact that there are times where the plant is unoccupied. This is again hard to verify due to the site not being in action during the research. The intention of building the shelter was that the protection from the heat and rain would mean the guard would be present rather than leaving in worse weather. A probability of 100% that the guard is present is used for modelling the site after the rehabilitation with the shelter and the fence, to provide a best-case scenario for the rehabilitations impact. The fence also makes stealing sludge more difficult for farmers if the guard is present at the site, though it is still possible for them to negotiate with the guard and bribe them to steal sludge. It

is also still possible for the private sector operators to negotiate with the guard and bribe them after the rehabilitation as well.

7.4.1.2 Modelling Approach

Having built a model of the interactions between the farmers, private sector and the guard at the central treatment plant, which leads to waste either being disposed illegally or used by farmers, adaptations are modelled to see if any changes could affect these interactions and improve treatment. The first adaptation is that being implemented by the City Council currently which is to build a fence to better protect the site and a shelter that the guard can stay in when the weather is worse rather than leaving in rainy or hot times. The main effect this would have is that the guard would more likely be there to interact with both the private sector and farmers. For this reason the modelling of the effect of the shelter is to have the guard present with a probability of 100%, which may be an overestimate of the efficacy of the change but is good to explore the maximum possible potential change from the fence being implemented. The second adaptation modelled is the change between a per visit tariff and a per month tariff charged to the private sector.

The modelling system for treatment has less path dependency than the Skyloo adoption model, as the main changes in behaviour are in probabilities of different actions from agents based on the payoff of behaviours. The payoff remains the same within the model however, so the behaviour tends towards a similar value for each experiment, whereas the Skyloo model spread of adoption has larger tendancy to vary in adoption and profit based on the people who adopt technology initially and the network structure.

In the treatment plant case, model runs are completed for both monthly and per visit tariffs before and after the rehabilitation being implemented by the government for varying criterias of price, assumed sludge value, bribes willingness to pay/receive, and bribe value. This allows the experimental model to assess which criteria has the most influence on the output and therefore which data gaps would be most important to fill to get a more realistic assessment of future functionality.

Each model is run for 250 repeats over 2,000 ticks, with each tick representing a day. This timescale is chosen as it was shown in initial runs to be long enough for agents to reach a static behaviour of probabilities of disposing/enforcing. 250

repeats are chosen for a balance of ensuring reliability of data and also being able to process and analyse results for multiple varying criteria.

7.4.2 Results

7.4.2.1 Tariff Structures Before and After Rehabilitation

As Figure 7-8 to Figure 7-11 show, the effect of the rehabilitation plan on the level of waste safely disposed is limited in terms of improving the amount of safe treatment. The dumping tariff and low disposal fine means that the most economically beneficial behaviour to the private sector tanker is to dump illegally on their own land whether they are fined or not. The main effect the rehabilitation has is on the amount of sludge that is stolen from the treatment plant by farmers, as the guard is always there and the ability to enforce higher fines and the risk to farmers combined with their limited carrying capacity for sludge compared to a truck full makes them less likely to steal the sludge. The amount of sludge disposed illegally is similar for all models as shown in Figure 7-11, and the amount of cash for the guards is similar for both tariff structures and only changes before or after the rehabilitation.

There is a large initial peak in cash flows from the assembly after 6 months when the first lot of compost is sold. This is likely an overestimate due to time it takes for the agents to adjust their behaviours towards a tendency of rarely disposing at the site giving an over-estimate of the sludge that can be sold at first. The only other implication to take is that the increased revenues available from using monthly tariffs instead of visit tariffs could perhaps be put towards increased enforcement and salary for the guard which may help to improve the operation. This opportunity could be explored in further models to look at the way that agents act and re-act more within the model.

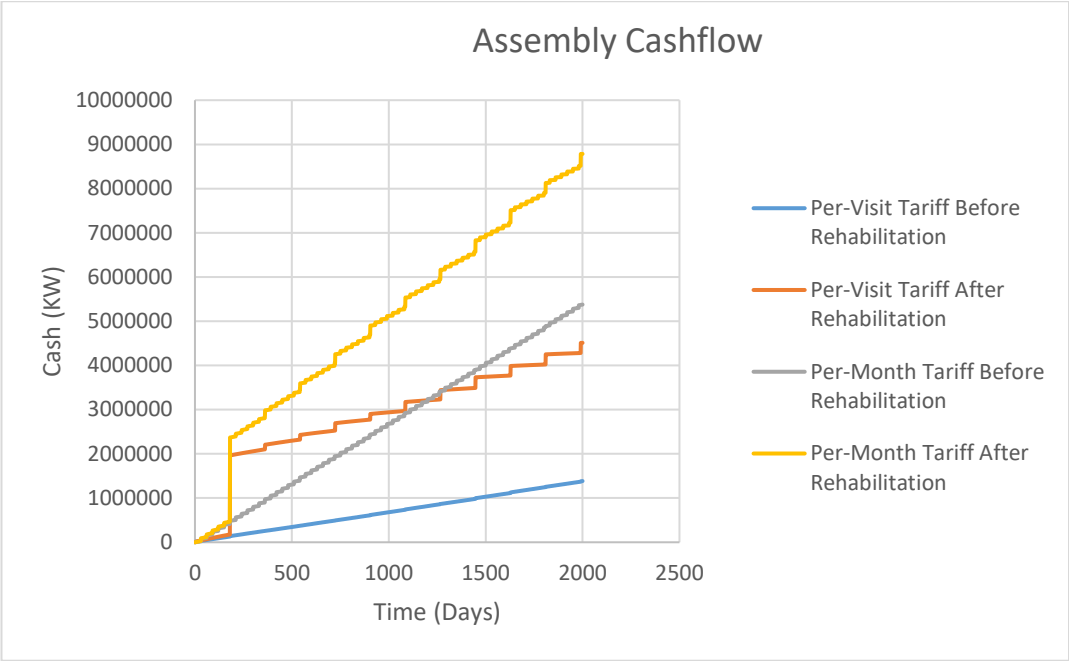

Figure 7-8: Average assembly cashflow from model runs of treatment plant ABM before and after rehabilitation with different tariff structures

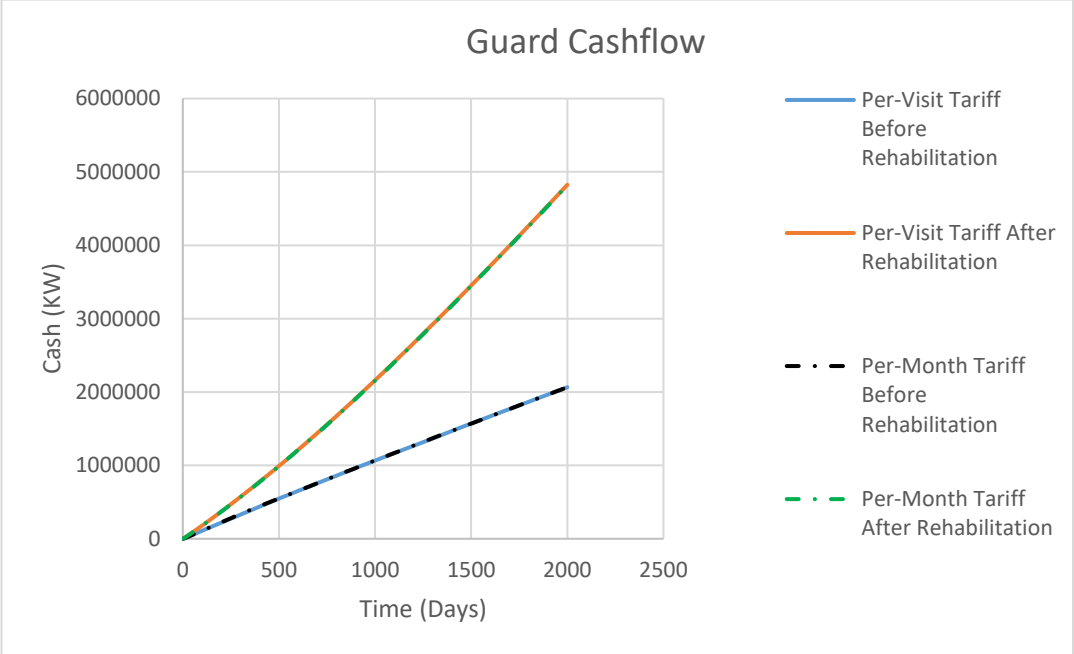

Figure 7-9: Average guard cashflow from model runs of treatment plant ABM before and after rehabilitation with different tariff structures

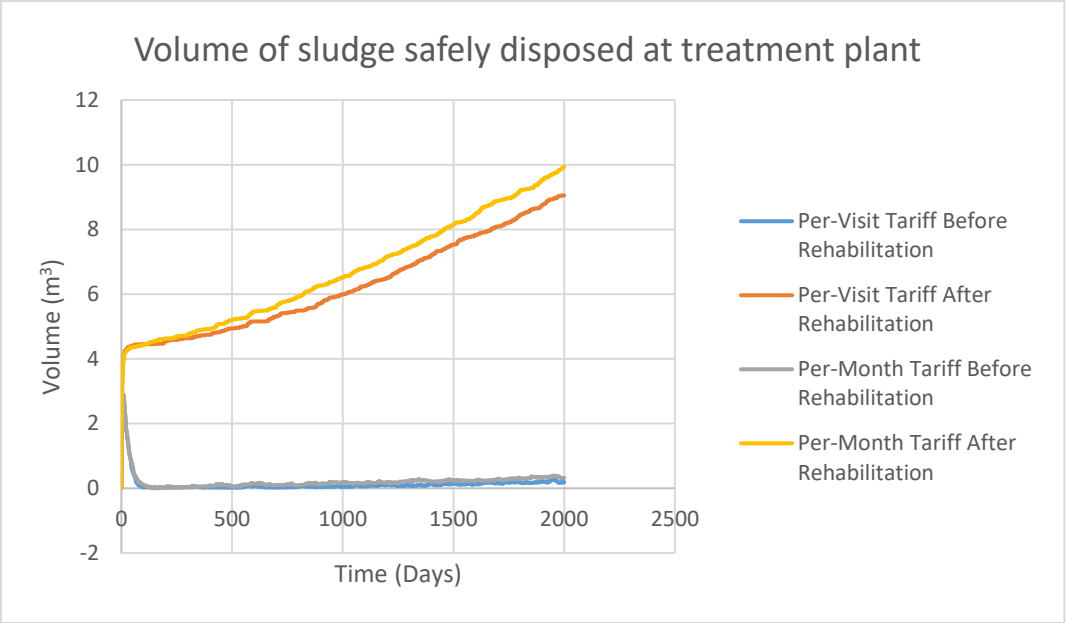

Figure 7-10: Average safely disposed sludge from model runs of treatment plant ABM before and after rehabilitation with different tariff structures

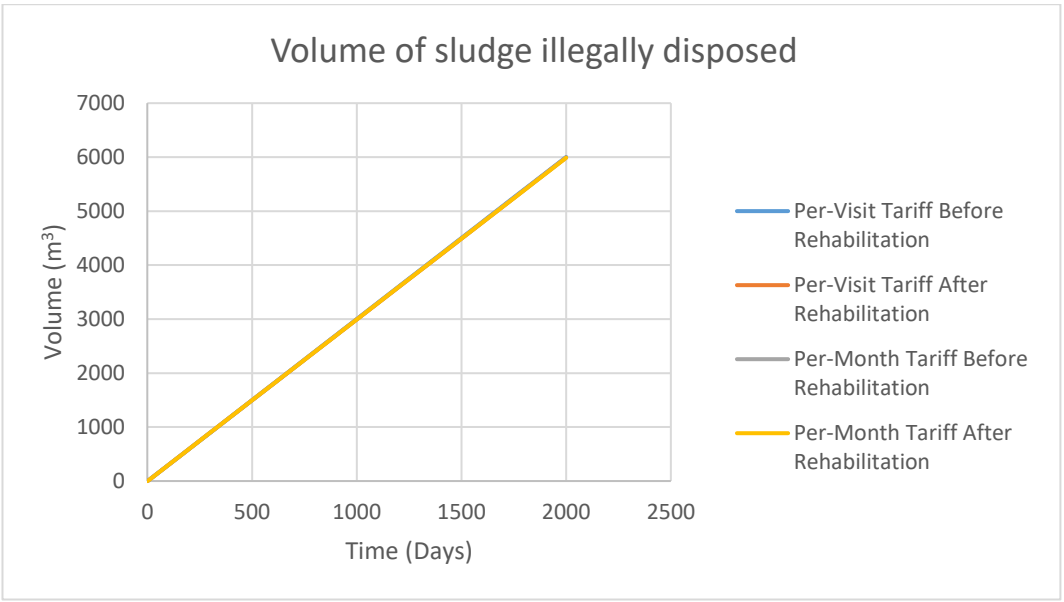

Figure 7-11: Average Illegally disposed sludge from model runs of treatment plant ABM before and after rehabilitation with different tariff structures

7.4.2.2 Different Policy Approaches

7.4.2.2.1 Pricing Strategy

The effects of different pricing levels, whether per visit or per month, are looked at on the average final values of cash, disposed waste and stolen waste in Table 7-4 and Table 7-5. The effect of increasing monthly prices on treatment efficiency is limited as this does not affect the modelled economic choices with the guard and the

truck at the point of disposal. However, this might be unrealistic at a certain point where the tariffs are simply too high for the private sector. Up to a point it is more logical that increasing a monthly tariff has less of a disincentive for disposing waste properly for the private sector than increasing a tariff that is charged every time a truck arrives. Table 7-5 shows that increasing per visit tariffs has a negative effect on the amount of waste that is treated, and the amount of cost recovered by the assembly. This is because the increased cost of safe disposal increases the relative benefit to the private sector of paying a bribe to dispose on their own land near the site.

	Monthly - Before Reahbilitation				
Price Effect	Assembly Cash (MKmillion)	Guard Cash (MKmillion)	Illegally Disposed Volume (m^3)	Stolen Volume(m^3)	Safely Disposed Volume (m^3)
MK 40,000	13.22	2.02	5,980.9	17.20	1.76
MK 60,000	14.55	2.01	5,978.3	16.92	1.65
MK 80,000	15.82	2.02	5,981.2	16.66	1.65
MK 100,000	17.11	2.02	5,981.3	16.57	1.70
	Monthly - After Rehabilitation				
	Assembly Cash (MKmillion)	Guard Cash (MKmillion)	Illegally Disposed Volume (m^3)	Stolen Volume(m^3)	Safely Disposed Volume (m^3)
MK 40,000	47.49	0.25	5,958.4	0.00	39.27
MK 60,000	48.14	0.25	5,959.1	0.00	37.72
MK 80,000	49.33	0.25	5,967.4	0.00	37.30
MK 100,000	50.91	0.25	5,960.3	0.00	38.04

Table 7-4: Effect of different monthly tariffs on average final performance of treatment plant in ABM

	Per Visit - Before Reahbilitation				
	Assembly Cash (MKmillion)	Guard Cash (MKmillion)	Illegally Disposed Volume (m^3)	Stolen Volume(m^3)	Safely Disposed Volume (m^3)
MK 6,000	10.31	2.02	5,987.7	11.83	1.03
MK 9,000	10.18	2.03	5,989.3	9.84	0.62
MK 12,000	10.17	2.02	5,991.2	7.79	0.50
MK 15,000	10.02	2.02	5,994.0	6.18	0.22
	Per Visit - After Rehabilitation				
	Assembly Cash (MKmillion)	Guard Cash (MKmillion)	Illegally Disposed Volume (m^3)	Stolen Volume(m^3)	Safely Disposed Volume (m^3)
MK 6,000	38.80	0.26	5,972.1	0.00	23.81
MK 9,000	36.08	0.25	5,981.4	0.00	16.96
MK 12,000	33.49	0.25	5,997.7	0.00	10.34
MK 15,000	31.35	0.25	5,990.9	0.00	4.94

Table 7-5: Effect of different per visit tariffs on final performance of treatment plant in ABM

These initial results looking at tariff structures suggest that firstly, monthly tariffs are more beneficial for the assembly management of the site even at a lower rate than what could be potentially recovered by charging per trip in cases of low disposal. The second finding is that increasing monthly tariffs has a less pronounced impact on treatment and cost recovery, as it does not increase the disincentive to disposing safely for the private sector. This is important for a country with a high rate of inflation where each price increase could bring minimal disruption if the tariffs are better structured.

7.4.2.2.2 Fines

Table 7-6 shows the effect of increasing disposal fines for the private sector on the performance of the treatment plant. This is assuming that the guards are able to enforce the fines each time, which may be an over-optimistic simplification made for modelling. What it does show is that the ability to enforce higher fines does have a slight improvement in treatment and assembly fees collected which may enable further enforcement and investment.

	Monthly - Before Reahbilitation				
Fine Effect	Assembly Cash (MKmillion)	Guard Cash (MKmillion)	Illegally Disposed Volume (m^3)	Stolen Volume(m^3)	Safely Disposed Volume (m^3)
MK 2,000	5.38	2.07	5,994.0	7.15	0.32
MK 6,000	8.14	2.05	5,989.7	9.88	0.72
MK 10,000	11.04	2.04	5,988.5	12.52	1.28
MK 15,000	14.52	2.02	5,974.1	17.33	1.72
	Monthly - After Rehabilitation				
	Assembly Cash (MKmillion)	Guard Cash (MKmillion)	Illegally Disposed Volume (m^3)	Stolen Volume(m^3)	Safely Disposed Volume (m^3)
MK 2,000	8.78	4.82	5,988.2	0.00	9.94
MK 6,000	21.69	0.63	5,978.4	0.00	16.99
MK 10,000	33.32	0.34	5,976.1	0.00	25.53
MK 15,000	48.41	0.26	5,959.9	0.00	38.28
	Per Visit - Before Reahbilitation				
	Assembly Cash (MKmillion)	Guard Cash (MKmillion)	Illegally Disposed Volume (m^3)	Stolen Volume(m^3)	Safely Disposed Volume (m^3)
MK 2,000	1.38	2.07	6,002.6	6.53	0.18
MK 6,000	4.01	2.05	6,000.8	6.17	0.23
MK 10,000	6.73	2.03	5,997.3	6.53	0.37
MK 15,000	10.22	2.03	5,993.1	10.02	0.75
	Per Visit - After Rehabilitation				
	Assembly Cash (MKmillion)	Guard Cash (MKmillion)	Illegally Disposed Volume (m^3)	Stolen Volume(m^3)	Safely Disposed Volume (m^3)
MK 2,000	4.51	4.82	5,992.3	0.00	9.05
MK 6,000	13.24	0.62	5,987.0	0.00	5.58
MK 10,000	21.80	0.35	5,995.9	0.00	6.31
MK 15,000	36.21	0.25	5,973.8	0.00	17.30

Table 7-6: Effect of different disposal fines on final performance of treatment plant in ABM

7.4.2.3 Sensitivity Analysis

From Table 7-7 the variation in sludge value mainly seems to affect how much faecal sludge the private sector dispose at the site, and if any is disposed farmers will use it when there is no guard in the no-fence scenario but will not risk arrest otherwise. It also shows that for varying levels of value the monthly tariff is still more effective at ensuring treatment of faecal sludge, if only a limited amount.

	Monthly - Before Reahbilitation				
Fine Effect	Assembly Cash (MKmillion)	Guard Cash (MKmillion)	Illegally Disposed Volume (m^3)	Stolen Volume(m^3)	Safely Disposed Volume (m^3)
MK500	15.18	1.92	5,891.1	90.89	12.16
MK2,500	14.51	2.02	5,972.3	27.24	2.87
MK5,000	14.55	2.02	5,980.5	17.18	1.75
MK7,500	14.38	2.01	5,984.4	13.38	0.96
MK10,000	14.50	2.01	5,992.0	10.75	0.84
	Monthly - After Rehabilitation				
	Assembly Cash (MKmillion)	Guard Cash (MKmillion)	Illegally Disposed Volume (m^3)	Stolen Volume(m^3)	Safely Disposed Volume (m^3)
MK500	40.34	0.49	5,796.9	0.00	201.22
MK2,500	44.77	0.29	5,946.9	0.00	58.93
MK5,000	48.24	0.25	5,961.9	0.00	37.94
MK7,500	50.43	0.24	5,970.9	0.00	28.89
MK10,000	52.54	0.23	5,976.4	0.00	24.25
	Per Visit - Before Reahbilitation				
	Assembly Cash (MKmillion)	Guard Cash (MKmillion)	Illegally Disposed Volume (m^3)	Stolen Volume(m^3)	Safely Disposed Volume (m^3)
MK500	11.25	1.95	5,948.9	50.30	4.81
MK2,500	10.36	2.02	5,978.1	15.53	1.34
MK5,000	10.23	2.02	6,001.6	10.13	0.75
MK7,500	10.29	2.02	5,985.5	7.76	0.62
MK10,000	10.37	2.02	5,991.4	6.72	0.58
	Per Visit - After Rehabilitation				
	Assembly Cash (MKmillion)	Guard Cash (MKmillion)	Illegally Disposed Volume (m^3)	Stolen Volume(m^3)	Safely Disposed Volume (m^3)
MK500	32.49	0.48	5,913.8	0.00	82.51
MK2,500	34.74	0.29	5,966.4	0.00	27.20
MK5,000	36.25	0.25	5,994.1	0.00	17.32
MK7,500	37.39	0.24	5,987.2	0.00	13.44
MK10,000	38.88	0.24	5,986.4	0.00	12.05

Table 7-7: Effect of different sludge value on final performance of treatment plant in ABM

From Table 7-8 the variation of the bribe multiplier, which multiplies the effective payoff of bribes for the guard, has a large effect on the revenue collection of the assembly particularly after the rehabilitation. This makes sense as after the rehabilitation there is 100% probability of the guard being present, so his willingness to take bribes is more influential than in the model runs before rehabilitation where 35% of the time the guard is not there. This is still quite a simplistic measure of guard behaviour but without interview still serves a basic purpose and shows the importance of the guards behaviour to the success of the treatment plant management. There is a sharp reduction in assembly cash flows and treated waste when the bribe multiplier is higher than six as this is the point at which the utility value of taking a bribe is effectively higher than the disposal fine for the guard, leading to him taking bribes more often than not. The other aspect of this result is that again a monthly tariff is shown to be more effective for varying levels of bribe multiplier.

Bribe Multiplier Effect	Monthly - Before Reahbilitation				
	Assembly Cash (MKmillion)	Guard Cash (MKmillion)	Illegally Disposed Volume (m^3)	Stolen Volume(m^3)	Safely Disposed Volume (m^3)
1	14.52	2.02	5,974.1	5,974.10	1.72
2	14.41	2.04	5,975.1	5,975.10	1.66
4	14.42	2.05	5,991.9	5,991.92	1.73
6	14.25	2.07	5,973.4	5,973.45	1.72
8	14.19	2.07	5,978.8	5,978.81	1.65
	Monthly - After Rehabilitation				
	Assembly Cash (MKmillion)	Guard Cash (MKmillion)	Illegally Disposed Volume (m^3)	Stolen Volume(m^3)	Safely Disposed Volume (m^3)
1	48.41	0.26	5,959.9	0.00	38.28
2	47.85	0.29	5,967.2	0.00	37.37
4	45.89	0.63	5,966.5	0.00	36.59
6	11.94	5.61	5,988.4	0.00	13.76
8	9.40	5.95	5,990.7	0.00	11.52
	Per Visit - Before Reahbilitation				
	Assembly Cash (MKmillion)	Guard Cash (MKmillion)	Illegally Disposed Volume (m^3)	Stolen Volume(m^3)	Safely Disposed Volume (m^3)
1	10.22	2.03	5,993.1	10.02	0.75
2	10.23	2.03	5,988.4	10.05	0.86
4	10.13	2.05	5,988.4	9.81	0.98
6	10.01	2.07	5,984.2	9.83	0.76
8	9.80	2.09	5,986.2	9.43	0.55
	Per Visit - After Rehabilitation				
	Assembly Cash (MKmillion)	Guard Cash (MKmillion)	Illegally Disposed Volume (m^3)	Stolen Volume(m^3)	Safely Disposed Volume (m^3)
1	36.21	0.25	5,973.8	0.00	17.30
2	35.96	0.29	5,988.6	0.00	17.13
4	34.08	0.63	5,985.5	0.00	16.59
6	6.95	5.62	5,978.2	0.00	11.07
8	5.02	5.95	5,978.1	0.00	10.37

Table 7-8: Effect of bribe guard payoff multipliers on final performance of treatment plant in ABM

Overall across all the results there is a clear indication that the disposal fines are not sufficient to properly enforce proper disposal from the private sector, and that the private sector behaviour could be improved by introducing monthly tariffs instead. Beyond that the main effect of policies and the rehabilitation is targeted at the farmers rather than the private sector which seems disproportionate due to the limited environmental effect of reuse compared with the effect of large scale illegal disposal of sludge. Policy and enforcement can be more effective if the sludge is not seen to be of much value to farmers and the private sector but if it is seen as more valuable it is harder to prevent. From this one of the main gaps of data that would be important to fill to understand would be the guard's behaviour. A more detailed nutrient analysis and value perception of sludge for the individual agents rather than the singular value currently used would also improve the model of the treatment plant.

7.4.2.4 High Enforcement and Arrest Model

To look at the possibility for higher enforcement and legislation to improve the treatment plant, a higher disposal fines and farmer fines of MK150,000 (USD207)

are used in combination with a lower sludge value of MK1,000 (USD1.38) per 50kg to assess if this improves the operation of the plant. The law is also assumed to be fully enforced by the guard rather than based on game theory. This would perhaps be achieved by: hiring multiplied guards, increasing guard salaries and increasing checks on the guard. The results are shown in Figure 7-12 and Figure 7-13. The high enforcement and high fine policy has a large increase in safely disposed volumes and cash flow to the assembly from sludge sales. This is mainly dependent on high volumes of sludge being disposed, and is also dependent on the possibility and relative cost of increasing and improving enforcement.

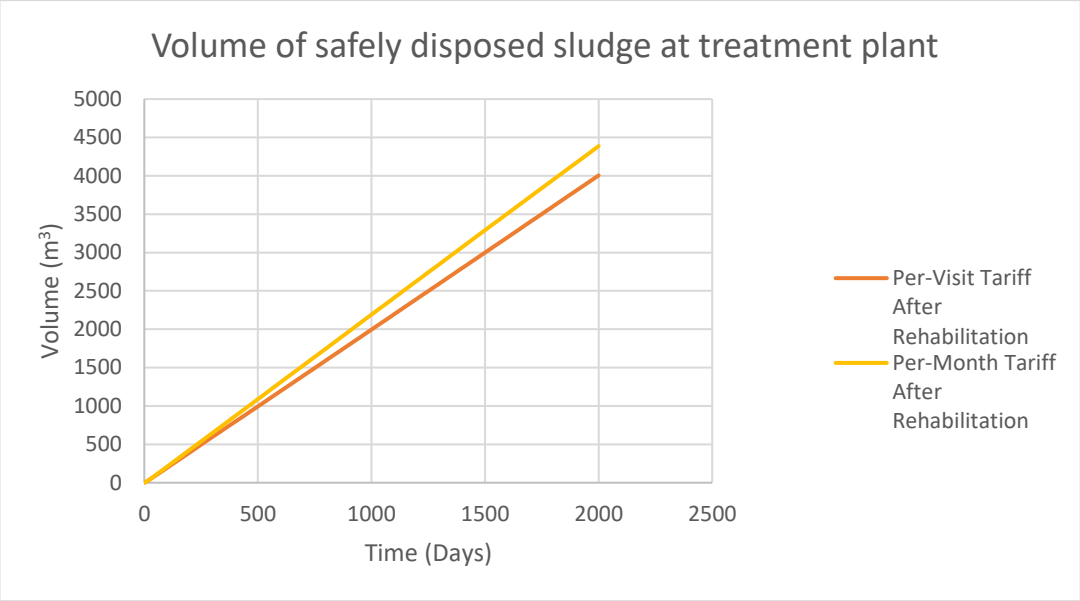

Figure 7-12: Average safely disposed volume from model runs of treatment plant ABM in high-enforcement scenario

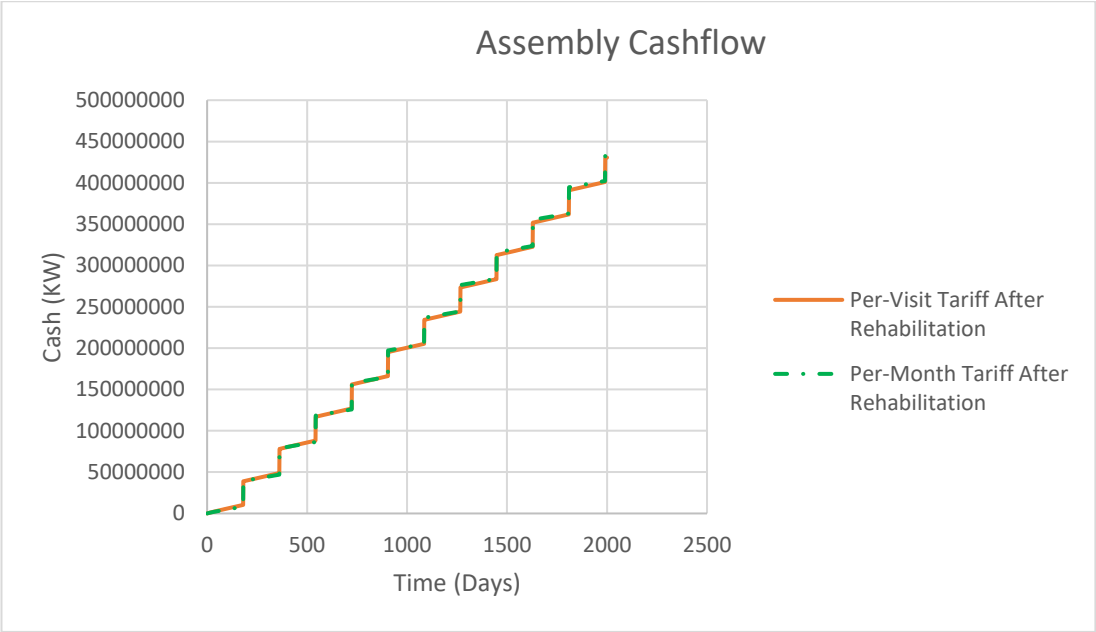

Figure 7-13: Average assembly cashflow from model runs of treatment plant ABM in high-enforcement scenario

7.5 Limitations of Modelling Approaches

7.5.1 Skyloo Adoption

7.5.1.1 Modelling Capacity

The main limitation to the modelling of Skyloo adoption was computing capacity for processing and running simulations using spatial data and large numbers of agents. Even a small-world network simulation with 3,000 linked agents had a slow run time, taking days to compute 1,000 runs of the model. This is a serious logistical consumption of time for ABM as an approach to simulation. In future applications streamlining the modelling process would be important to enable thorough sensitivity analysis and parameter variations. Whilst the computing power available for conducting modelling experiments was limited for a university science school context it is likely to be more than that available to design teams in Sub-Saharan Africa. The lack of computing power means that it was not within the scope of this research to conduct a thorough sensitivity analysis for data and modelling decision impact on the output. This would have helped to identify which factors have the most effect on the output and therefore which are most important to understand.

7.5.1.2 Input Data Limitations

As discussed in 7.4.1.1 there were many limitations in data and assumptions used to make a working model of Skyloos as a business; more realistic input data could

have made the model more useful to organisations considering building Skyloos. The major limitations are listed below:

- Monthly business cost
- Economic affordability
- Adoption process
- Unadoption process
- Network set up
- Spread through networks
- Spatial data GIS limitations: road interactions and size, and flood vulnerability

Limitations such as the business costs or flood vulnerability could be improved with positivistic data collection methods such as structured interviews. The model framework used, such as the structures of the social networks and adoption processes, could be investigated in more detail with surveys and semi-structured interviews. This process may actually change and refine the structure of the model itself rather than input parameters. This seems the most important form of modelling assumptions to solve as this is the process of coding human decisions and at least if that is realistic then input data such as monthly costs can be refined if they are shown to have a big difference. The current structure is grounded in data from adopters and processes taken by businesses. Though the data from non-adopters as to how they choose and adopt technologies is limited. The choice of using social networks for modelling the diffusion of innovations is also limited in terms of its grounding in data from Mzuzu, though there were interviewees who mentioned adopting the Skyloos on recommendations from families. Because of the nature of the data collection as grounded theory there was not much time committed to looking at flood vulnerability and land usage for sanitation in terms of geospatial data. This led to relatively simple measures being used to represent the issues that were often drivers for Skyloo adoption. The first issue of flood vulnerability was modelled based on observations of being more prominent in ‘dambo’ areas around water bodies. The issue of land was measured only as a relative measure to other houses. A more sophisticated model could have used the space and the effective space of a latrine and regularity of requirements to dig based on groundwater levels. This would have required data about soil quality, land use and further modelling capacity that was not available within this research.

7.5.1.3 Post-Adoption Usage of Skyloos

Another limitation of the model as an exploration of how Skyloos can contribute to treatment and reuse of faecal sludge as a sustainable business was that it did not look at how Skyloos were managed after adoption. Considering the issues found in the data around land ownership, disabilities, and use for children the way that composting toilets are maintained and used and the impact this has on treatment of faecal sludge would be an important study though it would require an extra level of sophistication in the model that was beyond the scope of this model.

7.5.1.4 User Feedback

One aspect missing from the modelling process is that of user feedback. This was used in (Osman, 2012) to validate modelling approaches used for water management and is a useful way of ensuring that models actually reflect human behaviour. As the model was only designed and built after the first fieldwork stage without the opportunity to return this was not possible, though it could have been a particularly useful way to help present assumptions to users and then get feedback on where the model was/not realistic. Future use of ABM would be greatly improved with user feedback iteratively used as part of the modelling process. In the case of Skyloo adoption interviews with implementing businesses could have been conducted to present, validate and refine: The success of marketing processes, costs of production and implementation, why customers adopt technology. Interviews, focus groups or participatory sessions could also be used with households who both have and have not adopted Skyloo technologies to refine and validate: the social network diffusion assumptions, how space and flooding issues affect latrine sustainability as a household sanitation option, drivers for adoption and economic affordability. City council members may also have been able to provide better data of land ownership and flood vulnerability, though land data may be limited in informal areas such as those studied in Mzuzu.

7.5.2 Treatment Interaction

7.5.2.1 Guard interview and data

The most obvious limitation, which can be seen in the large variation of results from varying the bribe multiplier to symbolise guard behaviour, is the lack of observation or interviews with the guard operating the treatment site. Without this data it is hard to build a fully realistic behaviour model. The model was still able to demonstrate that as guards were willing to take bribes to not enforce legislation, the rehabilitation

and use of a shelter will not significantly affect the treatment operation. More detailed investigations may help to assess this with more complex modelling assumptions.

7.5.2.2 Costs of Maintenance

The other gap in knowledge that could be more effectively looked at with feedback from city council members and people in Mzuzu is the costs of replacing materials for the composting site to ensure regular maintenance. This was again difficult to find out as the site was not being operated at the time. This would help to assess in more detail what level of enforcement and sludge sales would keep the site running, but could easily be added in to any modelling approach.

7.5.2.3 Effect of tariffs on business

The other data that is limited is how the monthly tariffs may affect business operations. There is obviously an upper limit at which a 'licensing fee' model would be prohibitive to the business being able to afford it. Without operational data and a financial analysis of business activity, which is difficult to get, it is hard to assess where a reasonable tariff would suit everyone.

7.5.2.4 Reaction within model- if there's more money can you enforce the law more?

For modelling simplicity and limited data about interactions, payoffs for agents from each interaction remain static within each model run. For example the city council does not change dumping tariffs, fines or enforcement strategy within a model run. This allows for faster modelling and does not add in extra complexity where there is no data. On the other hand it is a simplification to assume that the agents do not react to situations within the model. At this stage there is not enough data about the reactions and changing relationships between the agents in the model, so it would only add unjustified complexity to the model to simulate reactions. The use of static payoff values within each model run is still able to produce results about the effects of different policies in a quick, efficient manner.

7.5.2.5 Political Connections and Assumptions of guard power for fining

The regularity of fines within the model is unrealistic and is used as a measure of risk, but it is unlikely that it is enforced every time, particularly considering the political power of the private sector tankers they are trying to enforce legislation on. This leads to an overestimate of assembly cash flow from fines within the model, whereas the risk is likely to be lower to actors in reality.

7.5.2.6 Data about operation after rehabilitation

The missing data around how the treatment site is operating after the rehabilitation means that the model is only based on an assumption that it has made the prevention of farmers stealing sludge easier for the assembly and that the guard is present at the site. In reality the model would ideally be calibrated with current operating data to improve its use for assessing the potential of different tariff and enforcement approaches.

7.5.2.7 Volume and Quality of Sludge

The volume of sludge collected and disposed within Mzuzu currently has a large influence on the economic potential of composting for the government so there needs to be better data of how much waste could currently be disposed and the economic value of treating this as well as the public health and environmental benefits.

7.5.2.8 User Feedback

Similar to the Skyloo adoption model, this model of interactions could be largely improved with feedback on how behaviour is modelled from the agents themselves. This would serve the purpose of modelling behaviour more effectively but also being a tool for collaborative multi-stakeholder design. The extent to which ABM can be carried out collaboratively with participants is also likely to correlate with the extent to which it can successfully simulate socio-technical systems.

7.6 Conclusion

The conclusion of this chapter looks at both the results of the modelling of Mzuzu sanitation systems using ABM, but also the efficacy of ABM as a method for simulating socio-technical sanitation systems.

7.6.1 Agent-Based Modelling Results

For modelling the adoption of Skyloo toilets, the outputs showed and emphasised the qualitative results that linked the success and spread of sanitation on access to finance for businesses and households. The spread of the technology through social networks was also dependent on affordability of the technology. Depending on volume of sales and business costs initial lower prices were shown to have a pay-off in the longer run due to increased adoption and payback of loans.

For modelling of the treatment site the ABM showed an improvement in operation that could come from changing tariff collections from an at site per visit system to a

monthly licensing fee for the private sector. This reduces the disincentive to the private sector of disposing safely. The use of monthly tariffs also gives a predictable budget that the operations of the treatment plant can be run with. The ideal level of this monthly charge could be further looked at based on maintenance costs of the treatment site and consultation with private sector emptiers. The rehabilitation of the plant and assumed increased presence of the guard mainly affects the farmers using sludge on their own farms due to their limited transport ability and finance. It does not affect the private sector hugely as it is still within their ability to negotiate and pay more to illegally dispose sludge with the guard, whether he is present more often or not. The other option not modelled is simply the choice for the trucks to not go to the treatment site at all which is harder to enforce and legislate against. Though currently the fact that the private sectors land is by the treatment site makes going there beneficial to utilise the value of the sludge on their own farm. Increasing fines as planned from the cap of MK2,000 (USD2.76) may also help but this is dependent on the sludge's inherent value to actors within the model. This gap in information could be filled with better nutrient analysis and interviews and observation of agents after rehabilitation.

7.6.2 Agent-Based Modelling as a Design Tool

As a design tool both models have shown the possibility to integrate human behaviour into modelling of technical systems to improve the understanding and design of systems.

For Skyloo adoption the model demonstrated the ability of the ABM to look at social networks for diffusion of technology and effects of spatial factors such as land and flood vulnerability. Better data about decision processes of adopter and non-adopter households could help to look at adoption of sanitation technology more broadly. It could further allow the model to look beyond Skyloos alone and look at more affordable technologies as well. The main limitations lie in the ability of the research to collect sufficient qualitative data from users and non-users to build a more complex and realistic model of adoption. The main choice for future actors is between the complexity of additional data collection and modelling and the potential improvement of the model and implications for design approach. An ideal future development would also incorporate other technology options for households as Skyloos were found to be unsuitable for certain contexts. A broader look at different

technologies, with some that require emptying and disposal would be better and may also interact with the treatment model.

For the treatment site the use of Game Theory modelling approach showed the illegal disposal and use of sludge by farmers in Mzuzu as an economic decision process with values attached to different consequences. This was a relatively simple reflection of the reality but was grounded in data around interviews with actors, except for the guard himself who is a key agent. Having built this model, it was possible to look at the use of different policies and approaches to treatment and the effect it would have on the cash-flow of the assembly for operating the treatment plant and the level of safely disposed sludge. With extra data from the plant after rehabilitation the model could be improved to increasingly look at a balanced plan between the private sector and farmers and city council for managing the treatment plant.

8 Conclusion

8.1 Gaps in Literature

The following gaps in literature around sanitation in Sub-Saharan Africa were identified in section 2.6:

1. Gaps between grey literature and experience
2. Understanding of dynamics in smaller cities
3. Economics of resource recovery
4. Social acceptability of different resources
5. Effect of treatment initiatives on upstream faecal sludge management chain
6. Capacity of informal providers and private sector to provide treatment services
7. Understanding of interaction between technical and social factors

In terms of the gaps between grey literature published by NGOs and organisations and the actual experience the main contribution was the investigation of Skyloos in Mzuzu, where projects that had been ceased previously were observed to have not much follow up and many users had abandoned the technology and returned to pit latrines as it was not an appropriate technology for them. This demonstrates the gap between published work in grey literature from NGOs and organisations in sanitation and the actual project experience, particularly with the added factor of time. This needs to be considered for researchers and practitioners in this area when researching previous projects and their successes, that the longer-term effects of the project may not be published.

The research was able to look at the different dynamics associated with smaller cities by conducting case studies in Sunyani and Mzuzu. The main effect of city size seemed to be a reduction of transportation issues for emptying and transport of faecal sludge. In Sunyani there were few reports of illegal disposal of faecal sludge by the private sector whereas the literature found this to be an issue in larger cities. In Mzuzu transport distances were not the issue in faecal sludge management as often the private sector emptier disposed at his farm which was near to the treatment site, instead the issues were political and economic due to the dumping fees. This suggests that the reduced transport distances and the ability to place treatment sites closer to the city centre reduces the issue of faecal sludge transport in smaller African cities and presents more opportunities for sustainable models of

treatment and reuse of faecal sludge. This is an important consideration for policy makers and practitioners as it demonstrates that there could be opportunities for improved planning in smaller cities like Sunyani and Mzuzu which are projected to expand largely, but could have better infrastructure and management structures put in now whilst the cities are at a more manageable size.

In Mzuzu and Sunyani the economic potential for business models based on resource recovery and their impact on the upstream faecal sludge management chain were assessed. The economic potential of aquaculture, compost and biogas in Sunyani was assessed based on literature and stakeholder interviews due to limitations of the ability to conduct faecal sludge tests for a more detailed economic assessment. In Mzuzu the economics of skyloos were assessed and the potential revenues from selling compost centrally were assessed though the value of compost was variable according to different interviewees so a clear reliable economic assessment could not be made. Due to difficulties of interviewing actors about economics of different businesses and an inability to carry out faecal sludge testing and observation of the volume of faecal sludge collected in either city the economic understanding of both cities is limited. This could be improved with observation of volumes of faecal sludge collected in wet and dry seasons and faecal sludge testing for biogas production potential and nutrient analysis in Sunyani and Mzuzu respectively. This could be followed with supply chain analysis for the materials required for building and operating biogas plants and operating and maintaining the compost site in Mzuzu.

The case study approach was able to assess the social acceptability of different resources that can be recovered from faecal sludge in Sunyani and Mzuzu. In Sunyani biogas and compost were suitable whilst tilapia was not an appropriate option and there were some issues with duckweed. There were still some issues with biogas at household level particularly linked to the issue of diseases that were reported to be linked to public toilets, though centrally for electricity production it was a functional option for the local government. In Mzuzu there was a demonstrated perception of value in reusing faecal sludge in agriculture, though there were issues particularly with safe reuse by farmers and the appropriateness of Skyloo as a household technology. This demonstrates the connectivity between acceptability of different resources with the existing technical issues, as acceptability of reuse in Sunyani was closely tied with the public toilet system. So there are no generalisable

rules obtained from the case study about social acceptability of faecal sludge reuse, instead there is a need for local analysis before planning different approaches in cities. This is worthy of consideration for researchers, policy makers and practitioners, as findings from cities and successes of projects and technologies could be due to the institutional and social context rather than the technology or project itself so replicating a successful approach may be difficult.

In the small cities identified for case studies there were less informal providers found in literature and larger businesses with a monopoly on faecal sludge management. In both cities the companies have a capacity to be involved in treatment of faecal sludge and both showed an interest if the potential for reuse of faecal sludge was there: with the company in Sunyani already managing the solid waste management site and declaring some interest in biogas, whilst the owner of the company in Mzuzu was already using faecal sludge on his own land. Overall the results cannot be generalised from the case study, only that the different case studies found different scales and capacities of private sector actors for involvement in faecal sludge treatment and found less of the informal providers that existed in literature so the private sector capacity needs to be analysed with more cases. Again this needs to be considered by policy makers as there was a push in legislation and sanitation plans of both Malawi and Ghana to involve the private sector more and that they could solve barriers to sanitation though in different cities and areas they may not have the capacity to.

In terms of methods to better understand the socio-technical systems that are involved in sanitation the potential of ABM was explored and shown to be successful at modelling certain aspects of technological or social change in Mzuzu, Malawi. The usefulness of ABM is grounded in the level of data that can be collected and the ability to verify and enhance models with feedback from the users and stakeholders. This first approach towards ABM was produced in relative isolation due to limited time and money for fieldwork, but ideally in the future the tool should be calibrated more towards reflecting how changes affect stakeholders. For instance, building the model with the council who were working on the rehabilitation may demonstrate that their existing plans for management will have limited effects in terms of treatment efficiency. Then once the model has input from more stakeholders the results produced may be more valid and applicable to them, but as a first step ABM has demonstrable applications for modelling socio-technical systems such as those in

sanitation. This is worthy of consideration for follow up by other researchers to further look at how systems can be simulated and how this can enable improved project planning.

8.2 Overall Aim and Findings

In section 1 it was hypothesised that faecal sludge treatment with resource recovery could overcome economic and political barriers to faecal sludge management in Sub-Saharan Africa in the following ways:

- Profitable business models linked to sustainable treatment and re-use of waste would have less need for political regulation that is often lacking
- Resource recovery would provide funds that are currently lacking for maintenance and operation of systems
- Resource recovery models would stimulate demand for private sector involvement in the sanitation sector by providing profitable business models
- Resource recovery would stimulate demand for faecal sludge across the sanitation chain by identifying a value proposition in treating and re-using the end product

In Sunyani biogas with production of electricity was identified as a potential solution for treating waste from public toilets and organic waste from markets depending on the quality and quantity from sludge. This approach is being adopted in other cities in Ghana on a similar scale to what would be required in Sunyani, indicating it may be a worthwhile solution to investigate. Biogas is only suitable as a high value prospect for public toilet waste. This raises the question of how the remaining faecal sludge in the city can be treated in a sustainable way, and it is likely that it would depend on public funding to achieve the aims of encouraging the private sector meaning that the political barriers identified in Table 1-1 remain. It has also been demonstrated in literature in Ghana that the profits from public toilets lead to an incentive to maintain this system that can often be unhygienic. The introduction of a profitable biogas business dependent on public toilet waste may increase the political engagement in maintaining this system. Biogas for electricity as a whole city solution may still be a viable option, though it depends on a more detailed analysis of the quality and quantity of sludge collected in Sunyani. It is likely a full-city solution would be more dependent on either donor funding or government funding rather than private sector investment due to the reduced value proposition of private toilet waste.

In Mzuzu two systems of faecal sludge re-use were already being practiced: central composting of waste from septic tanks and household Skyloo composting toilets.

Skyloos were an effective system in terms of resource recovery as the household driver of harvesting compost encouraged proper operation and maintenance at household level reducing the need for political regulation and enforcement of management. The building and selling of Skyloos with access to finance was demonstrated as a financially viable model for private sector actors. The barrier to the success of Skyloos was social and economic, as it was not a financially accessible technology for some and was not an appropriate technology for many households due to lack of land for application of compost, landlord-tenant relationships and physical weakness or lack of finance and time to maintain the Skyloo.

There was a demonstrated demand for compost in Mzuzu, which the central treatment site could fill after rehabilitation. It is unlikely that the sales from compost will be sufficient to ensure proper operation and maintenance of the system as hypothesised in section 1 and any operational model will still be dependent on overcoming the current political barriers related to the relationship between the local government, private sector and surrounding farmers. On top of the planned rehabilitation to introduce a fence and a shelter for the guard, this could include introducing a monthly disposal tariff instead of a per visit tariff for the private sector emptying company and increasing fines and enforcement of legislation.

Overall models of faecal sludge treatment with resource recovery were identified that could contribute funding for maintenance and operation of systems and stimulate demand for private sector involvement in the sanitation sector. However, models of resource recovery were not sufficiently profitable to negate the need for enforcement and regulation and dumping fees would still likely be a necessary revenue stream for any business model so resource recovery would not stimulate a significant extra demand for collection of faecal sludge. Any improved treatment systems are still dependent on the relationships between the local governments and private sector actors so a drive towards understanding policy barriers as well as the technical and economic issues identified and addressed in this research is needed.

8.3 Further Research

The main avenues for further research in Sunyani would involve sampling of faecal sludge from public and private toilets and assessing viability for biogas production for electricity and more detailed interviews with the government as to how a government feed-in tariff structure could work. Beyond that the next stage would be assessing available sources of finance and the relative merits and drawbacks of each as access to finance was shown to be a key constraint to sanitation as a business.

In Mzuzu nutrient and contaminant sampling of faecal sludge and compost being used in agriculture, both from Skyloos and the treatment plant, could enhance the understanding and current use of sludge in agriculture. Long term observation of the rehabilitated treatment plant and the political interactions between the private sector and the local government would also help to verify and refine the ABM of the current treatment system. For adoption of composting toilets, a further qualitative study of adoption of sanitation technologies amongst households should be researched with the potential for multi-choice technologies to be provided with loan facilities.

Applying a similar research in different case studies of small cities would also enhance understanding of the potential for sustainable sanitation with reuse of faecal sludge in small African cities. Across the two case studies a large change in technologies, institutions and systems were identified showing that the success of sanitation systems is highly grounded in the socio-economic context.

8.4 Overall conclusion

Overall no technical system incorporating the economic and social factors was identified that could solve or remove the political barriers of failing sanitation in small African cities showing the need for political analysis and solutions as much as technical ones.

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Appendix A- Conference Paper submitted to WEDC 2016 Conference

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ENSURING AVAILABILITY AND SUSTAINABLE MANAGEMENT
OF WATER AND SANITATION FOR ALL

A socio-economic analysis of different approaches to faecal sludge treatment in Sunyani, Ghana

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REFEREED PAPER

With the SDGs moving beyond the focus on household sanitation facilities and aiming to halve the proportion of untreated wastewater and increase recycling and safe reuse, there is a need to look at new approaches to treatment. This study was conducted to investigate the socio-economic case for a resource recovery-based business model to fund faecal sludge treatment in Sunyani, Ghana. Semi-structured interviews were conducted with stakeholders including households, sanitation businesses and potential resource customers; together with observation and infrastructure mapping to assess the existing sanitation infrastructure and different options that could be implemented. Of the different resource recovery models investigated, biogas was the most acceptable option to customers whilst also providing a good business model to fund faecal sludge treatment, either as a decentralised system at public toilets where the fresh sludge is better for biogas production, or centrally at the existing disposal site.

Introduction

According to the Ghanaian government's own report (MLGRD, 2010), the level of faecal sludge treatment throughout all regions of the country is 'abysmal' with only 7 of 44 treatment plants functioning. There are often difficulties operating and maintaining technologies, with treatment plants in Accra and Kumasi breaking down due to component failure and poor maintenance, showing the need for new approaches to faecal sludge treatment. The government report places an emphasis on robust low-cost technologies that can handle the high BOD of faecal sludge from public toilets such as those often used by low-income communities. Even with simpler technologies there is a need for ongoing maintenance costs to be covered. The objective of this research was to assess the potential for different resources to be generated from faecal sludge treatment as a business model, and which of the options might provide the best profit incentive for long term management.

Method

A case study strategy was adopted to assess different options for faecal sludge treatment. Sunyani, a city located 125km North-West of Kumasi was chosen as the research location. It was chosen due to the limited level of existing research looking at faecal sludge management (FSM), the presence of a university for research support and its relatively small size, with a population of 125,000 in 2010 (Ghana Statistical Service, 2014). A city with limited information was chosen for the research to provide information about how treatment could operate in a different context with different stakeholders from the existing literature. The city's smaller size also means reduced distances and fewer informal, unplanned areas, making the FSM chain easier to manage up to treatment, providing a better environment for treatment than larger cities.

Mixed Methods were used to assess the possible different business models in Sunyani. Observation of vacuum truck driving routes, structured interviews with public toilet operators and infrastructure mapping were used to understand the existing infrastructure and identify businesses and stakeholders to speak to.

Semi-structured interviews were then used to assess the acceptability and profitability of different resource options and how they would fit with the existing infrastructure and providers. Potential customers were asked about the competitor products they used and why, how they would approach any new product, and concerns they would have about waste based resources. The different interviewees are shown in table 1.

Household interviews were conducted in two different areas of Sunyani. Odumase, the first area, is a small town on the outskirts, about 9km from the disposal point, so it was chosen to study the possibility of decentralised treatment. Due to Sunyani's size it has less of a class division between areas than in the larger Ghanaian cities like Kumasi and Accra, so a central area proximate to identified public toilets and gas filling stations was chosen as the second study area for household interviews, shown in figure 1. Two farming villages were chosen for farmer interviews. Wasasua is made up of farmers mostly from Sunyani area who owned the land they farmed, whilst Jato Nkwanta is mainly made up of migrants from the northern regions who farmed the land and gave a share of the produce to the owners.

Table 1. Interviews Conducted in Sunyani

Interview Type	Purpose	Number of Interviews Conducted
Stakeholder Interview	Understand existing sanitation level and challenges in Sunyani	11
Household Interview	Understand satisfaction with existing sanitation and perceptions of biogas and tilapia resource products	34
Farmer Interview	Understand perceptions of fertiliser resource product	30
Fish Farmer Interview	Understand perceptions of fish-feed resource product	4
Business Interview	Understand private-sector engagement in sanitation and economics and challenges of businesses	11

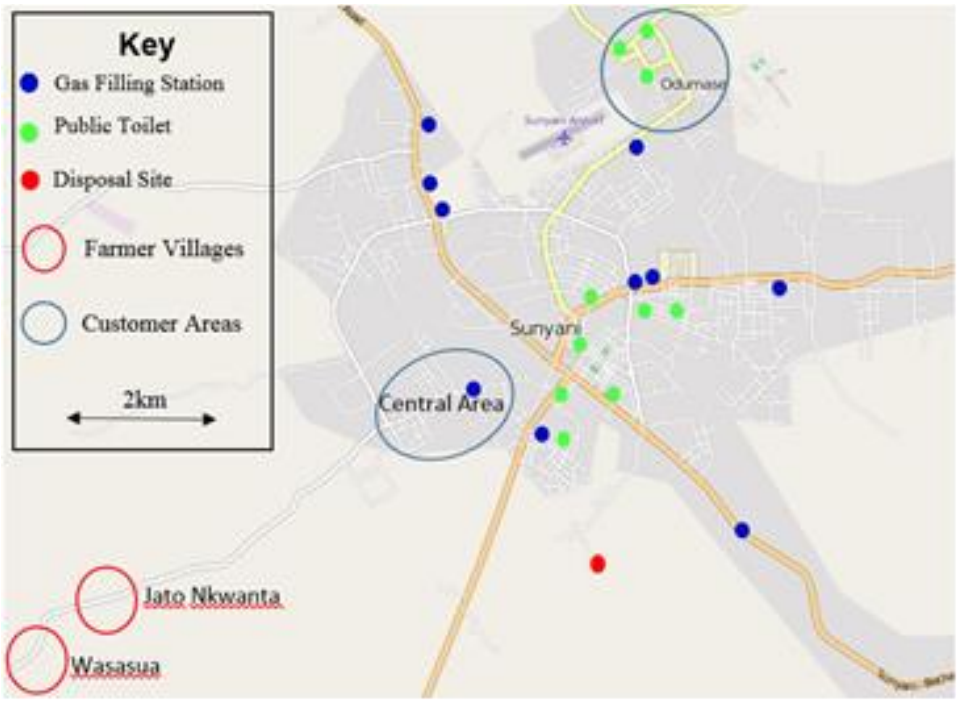

Figure 1. Infrastructure Map of Sunyani and Study Areas

Source: Map Data: © OpenStreetMap contributors

Results

Infrastructure Level

In terms of sanitation facilities, people use a mix of public and private toilets. There are 15 toilets that were surveyed and mapped within the municipality, shown in figure 1. There are 33 facilities in total but some of these were further away from the centre so were more difficult to visit. In addition to the Assembly (local government), there are two main companies who operate vacuum trucks for emptying toilets. The prison service, fire service and local polytechnic also have their own vacuum truck mainly for their own services rather than as a business. Solid and liquid waste is dumped at the same place. The road to the treatment site is currently very badly surfaced, is unusable during heavy rains and often causes trucks to get stuck.

The disposal site consists of a series of 6 treatment ponds that are no longer functioning. There are inefficiencies in funding management as dumping fees, 20 Cedis (1 Cedi=$3.81) per disposal, go straight to the Assembly budget, meaning they cannot easily be accessed for maintenance. This was clear when waiting a week for observation with the Assembly vacuum truck, as the truck crew were waiting for funds for fuel. This issue with finance and maintenance has led to the ponds becoming defunct and requiring large funds, 20,000 Cedis at the manager's estimate, to restore.

If restored the ponds could provide a basis for a resource-oriented business model, either by growing aquatic plants such as duckweed, or rearing fish directly in the ponds. The 15 acres of Assembly land at the disposal site could alternatively be used for a central biogas plant or composting plant to provide a model centred on biogas and fertiliser generation respectively. These four different resource options are investigated in semi-structured interviews based on their suitability to the existing infrastructure in Sunyani.

Resource Acceptance

Biogas

Biogas was the most well-known of the resources investigated in this study, with 14 of the 34 interviewees having some knowledge of the concept of biogas in discussions. It was also the resource in which the people responsible for sanitation in Sunyani were most interested and were hoping to produce. When the method of production was explained, most were open to the idea of using biogas as long as it was competitively priced.

There were some differences between customers in Odumase and town with regard to biogas. Firstly people in town mostly used liquefied petroleum gas (LPG) for cooking whilst those in Odumase used coal or wood, citing the expense of gas as prohibitive to buying. This is likely due to the upfront cost of canisters which started at 100 Cedis, enough to buy three months' coal. This means there might be marketing and innovative approaches required to replace coal and wood with biogas in Odumase and other lower income areas, whereas people in town who already use LPG are an easier market to access.

Cost was a large consideration for all interviewees when asked about using new fuels, with one interviewee saying *'We Ghanaians ….like cheap things. So if they introduce that one and it costs less … I think people will buy'*. In Odumase there was generally less openness to the idea of biogas with health concerns cited more often than in town. The public toilets had a widespread reputation in Odumase for spreading the disease 'whites', or candidiasis, which people believed was caused by heat rising from the toilets. This meant people in Odumase were less open to the idea of using biogas, though some still would, with one interviewee saying *'our food is grown with the faeces anyway'*. In town there were fewer concerns about health and more about practicalities of use. When asked what they would do if they were offered a new type of fuel when refilling a canister some people said *T* While others said that they would simply buy the new type and test it and compare it to the old.

Duckweed

Duckweed can be used as fish-feed, and can be grown on the surface of waste stabilisation ponds (WSP) for resource recovery (Hnoukpe Wendeou et al 2013). There is an association of 25 fish farmers growing tilapia in the surrounding area around Sunyani, who currently buy their fish-feed in Sunyani market. The four fish farmers interviewed all took their feeding advice from the fisheries department of the local government, so any decision to use duckweed would depend on advice from them. One fish farmer already used duckweed as a supplement as it grew on his fish pond and *'I came to the regional boss and told him about it and he encouraged me to keep it because before it was so much on the pond.'* when others were asked about the possibility of using new feed they would respond *'If we find a new one and the minister approves it, if it's approved then we will go and buy it. Until they ask us to buy I can't buy any food.'* One fish farmer was not keen on the idea as she had had to remove it from her own pond to prevent it affecting the water quality and damaging her fish, which can happen with a full cover of duckweed inhibiting oxygen diffusion and light penetration (Iqbal, 1999). Overall, for duckweed to be viable it would need to be done through the fisheries department who were open to the idea if they had *'information and background as to what duckweed can do… using duckweed and the results that they had using duckweed specifically maybe on tilapia.'*

Tilapia

Rearing Tilapia directly in the tertiary ponds and selling to customers at the market was another option that can be more profitable than duckweed growing (Iqbal, 1999). This was the least acceptable option to people in the area as a waste-based resource. People made comments such as *'the ones in the sea sometimes people ease their selves so I don't eat fish.'* or *'I have eased myself and now going to throw it away so if growing tilapia I wouldn't buy'.* There was one interviewee from the Fanti region who was open to the idea as *'where I come from they have sea and sometimes when we swim and when the waste is taken it is dropped in the sea so I know it happens.'* but otherwise it was not acceptable to people. Perhaps with community education it would be possible but the visceral opinions mean that it would be better to investigate alternative resources.

Fertiliser

The idea of using excreta as a fertiliser was one well known in both villages when asked about the possibility of using in interviews, with people often having heard about it through word of mouth and as one said *'that's an old technology so farmers have used cow dung before and it made crops grow faster.'* The use of animal droppings on farms was quite common, particularly with those who raised their own animals, but some also borrowed from farmers as shown by the following interviews*: 'I know I already*

have 3.5 acres where I apply faeces from poultry so I know it is good.', 'there is no money to buy the fertiliser so sometimes I go to the poultry farming and ask for droppings to apply to crops.' The latter interviewee also highlights the issue of cost of fertiliser, particularly in Jato Nkwanta where the farmers were of lower income and did not own the land. They did not use fertiliser because: *'There is no money to buy the fertiliser so I just do it like that', 'My desire is to buy fertiliser but I don't have the money.'* A few farmers in Jato Nkwanta also cited issues with the landowner as to why they did not use fertiliser: *'the problem is still that the owner needs to share the costs for the fertiliser. If I buy my own I will be cheated.'*

The people who used fertiliser were open to the idea of using fertiliser from treated faecal sludge. Their decision-making varied: for some *'The person (selling) is able to explain it well, how it functions, how it works then I would purchase one and see if it works well…. or if my brother bought some then I would follow and have a look'* or some who would *'try it and see the difference between the latter and the former.'*

Resource Production and Distribution

Biogas

Production of biogas would require construction and operation of a new biogas plant, which could either be done centrally at the disposal point or at public toilets, which are more suitable for biogas as it has stabilised less than latrine sludge (Strande et al 2014). Speaking to an academic at University of Energy and Natural Resources (UENR) in charge of the campus digester estimated a yield of 1.33litres/person.d so a toilet used by 300 people a day, which was typical in Sunyani, could expect to produce 146m^3/yr of biogas. The total waste in Sunyani is not known, but assuming that all 33 toilets have a similar rate of use there is a potential production of 4818m^3/yr. Based on a rate of 24-44litres/person.d (Colon et al 2015), a public toilet with 300 people a day would produce 2628-4818m^3 a year of biogas or 86700-159000m^3 a year across all toilets.

Currently people buy gas at filling stations throughout Sunyani shown in Figure 1. These have a similar distribution through Sunyani as the public toilets, so producing biogas and selling directly at public toilets is likely to be as accessible. If it was produced centrally it would likely need to be distributed to vending points in the city, which would raise issues due to the road condition.

Duckweed

Duckweed growth on the final ponds of treatment systems can yield around 20 t/h.yr (Iqbal, 1999). From satellite images, the three tertiary ponds have a total area of 736m^2 or 0.0736hectare, which could grow 1.47 tonnes a year. Currently fish farmers come from different surrounding towns and villages to buy prepared feed. If the duckweed is dried and pelleted it could also be sold prepared at local markets. Selling fresh would require regular distribution as fresh duckweed only lasts 3 days if kept cool and damp (Iqbal, 1999).

Tilapia

In a waste based rearing system it is possible to rear the fish tilapia at a yield of 6.7t/h.yr (Iqbal, 1999). This provides a yield of 493kg of fish per year from the tertiary ponds. Another business tried waste-based catfish rearing at densities of 4.72 and 2/m^2 (private communication). Using the lower estimate of 2/m^2 and a growth period of 6 months would yield 2944 fish/year, or 981.33kg/year assuming a fish size of 0.33kg which was the standard sale size at fish farms in Sunyani.

Fertiliser

Dried faecal sludge could be sold directly to farmers as a soil amendment at markets in Sunyani. Assuming a solids content of 35g/l (Diener, et al., 2014) and 216m^3 a year of faecal sludge from public toilets based on emptying frequency of once a fortnight that was given by public toilet owners, there is a total solids content of 7.56t/yr at a public toilet if sold directly there or 250 tonnes per year from all 33 toilets.

Economic Comparison

Biogas

LPG, the main competitor to biogas, is currently sold at filling stations for 1.72 Cedis per litre. Based on the estimate from the UENR academic (private communication) that biogas will last half as long a sales

price of 0.86 Cedis per litre is assumed. This would yield annual sales of 125,560 Cedis scaling up from the university toilet, and 2.26-4.14 million Cedis per year using the experimental production. Across all public toilets, revenues of 4.14 million and 74.58-136.62 million Cedis could be generated. The higher estimates of production may be more than the existing gas market in Sunyani. Only 2 filling stations had information about LPG sales for cooking, with estimated sales of 456m^3 and 294m^3 a year, or 912m^3 and 588m^3 biogas equivalent. If surplus was produced it could either be scrubbed for car use, with many cars already using LPG, or a marketing strategy for replacing wood and coal could be developed. Capital investment estimates for a single public toilet digester varied significantly, with the UENR academic estimating 150,000-190,000 Cedis (private communication) while a public toilet owner had been proposed to build a biogas digester for 50,000 Cedis. Operating the digesters would require at least one member of skilled staff. The varying costs and revenues suggest that a pilot would be important to understand the actual economic case for biogas.

Duckweed

Ranaan is the only source of complete fish feed sold in Sunyani, at a price of 80 Cedis for a 20kg bag. Duckweed would need to be sold in combination with a high carbohydrate source such as wheatbran to provide the full diet for tilapia. At 4 Cedis per kg a yearly revenue of 6,000 Cedis could be generated. In terms of capital cost the main expense is tied up in desilting and restoring the treatment ponds which was estimated at a cost of 20,000 Cedis by the manager of the site who was applying for funds. Other than that, staff would be required for pond maintenance and collecting the duckweed as it is highly labour intensive compared to standard WSP operation (Iqbal, 1999). There would also be fuel costs associated with the regular transport of the product if sold fresh.

Fish

At a sales price of around 12 Cedis per kg when the fish weigh 0.33 kg, annual tilapia sales could generate 5,916-11,775 Cedis. The capital costs would be the same as the duckweed with the main requirement being to restore the pond and maintain operation with staff. There are also capital costs associated with buying the initial stocking fish. Operation would again require staff, and possibly supplementary feed.

Fertiliser

As there is little market for faecal sludge as an agricultural product, it is hard to estimate the sale price that could be generated. With the use of poultry droppings it was often on a charitable basis between farmers without cash exchange so sales of $4/ton, or 15.2 Cedi/ton, are assumed based on other African cities (Diener, et al., 2014). All the sludge from 1 public toilet could be sold at 114 Cedis per year, or 3800 Cedis for all public toilets. As biogas production is expected to leave only around 17% of the total solids to be sold as fertiliser (Diener, et al., 2014), this equates to potential supplementary revenues of 20 Cedis per year or 646 Cedis per year for 1 and all public toilets respectively.

Institutional Arrangement

Whilst there is a social acceptance for a profitable business model centred on resource recovery from waste treatment, there would need to be a suitable institutional arrangement implemented for the profit driver to encourage uptake of such a business model. When discussing the possibility with one stakeholder it was clear *'In its current state it is not of interest to businesses as the fees for collection combined with the dumping fees are not economical to fund treatment of waste.*' From the managers of treatment within Sunyani this opinion was also shared that there are *'not enough staff no. one person at the disposal site but it's not enough to maintain. If independent would be able to keep budget and operate independently.'* So for a resource-oriented business model to be implemented in Sunyani there would need to be a change from the current institutional management to provide a profit incentive for resource recovery to be managed properly. This could either be done by setting up an independent company within the Assembly with profits passed to the Assembly or through contracting the management of the treatment plant.

Reflexivity

The issue of reflexivity has to be considered with the results, particularly relating to social acceptance and demand for different resources. Often the researcher's position as a comparatively wealthy European seemed to influence the results, as often people had the perception that the purpose of the research was to build a biogas digester/composting site for the community. This was particularly prevalent in the farming

communities where while someone was being interviewed saying they do not use fertiliser a friend came in and said they '*should agree more as it is an NGO who may give some.*' A similar issue often arose when discussing biogas and people would ask *'are you going to build?'* However, the fact that interviewees still almost unanimously rejected the idea of tilapia shows that the survey was not completely answered based on trying to please the interviewer, and most of the time people expressed conditions for buying.

Conclusion

This research aimed to assess which resource-based faecal sludge treatment models could provide the best profit driver to fund ongoing treatment in Sunyani, Ghana. A satisfactory demand and acceptability of waste-based fertiliser, fish feed and biogas was identified whilst waste-reared tilapia did not have market demand so would not function. Of the three different possible resource based models biogas has the largest profit driver, even based upon the lower estimate of the digester production at UENR. To fully assess the potential profit, better data would be needed on the quantity and quality of sludge in Sunyani, and for environmental reasons a treatment plan for the remaining sludge after resource recovery would be needed.

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Appendix B- Conference Paper submitted to WEDC 2018 Conference

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TRANSFORMATION TOWARDS SUSTAINABLE
AND RESILIENT WASH SERVICES

When faecal sludge reuse doesn't work: a look at access for the poorest and people with disabilities in urban Malawi

A. Mallory, R. Holm and M. Crapper (UK)

PAPER [OFFICE USE ONLY]

Reusing faecal sludge to generate value has the potential to contribute towards solving the issue of long term sanitation solutions in cities across Sub-Saharan Africa. This research was conducted to evaluate the potential for faecal sludge reuse in Malawi, and the difficulties and challenges to existing attempts at reuse in a city. We conducted 65 semi-structured interviews in a city of Malawi. The results show that two main approaches exist currently: The implementation of Skyloos as above ground household toilets which provide compost; and a central disposal site from which compost is illegally harvested. Both existing approaches to faecal sludge management and reuse were found to be inaccessible and not working when implemented for the poorest and people with disabilities.

Introduction

Access to sanitation in Sub-Saharan Africa has been shown to be an issue for people with disabilities (White, et al., 2016; Biran et al., 2018), with accessible design often failing and being cited as a large barrier by users. Treatment of faecal sludge in developing countries also often fails following construction due to low operational capacity and lack of finance for maintenance (Strande, et al., 2014). Malawi, a low-income country in Sub-Saharan Africa, has challenges in terms of providing safe sanitation and faecal sludge treatment in cities. Nationwide, 33% of the population relies on either unimproved sanitation facilities or practices open defecation (UNICEF and WHO, 2017).

One potential solution to limited treatment and improved household sanitation has been the building of ecological sanitation (Ecosan) facilities (Langergraber and Muelleger, 2005). Development projects in Malawi have used Skyloo toilets to solve the problem of treatment and reuse of faecal sludge in agriculture, high groundwater and lack of space for facilities. They are an adaptation of the Fossa Alterna, using two dry pits above ground surface that can be alternated whilst allowing the other pit to produce compost (Eawag, 2014). The raised pits prevents flooding and pit collapse that can be common in areas of high groundwater.

The economic potential for resource recovery from faecal sludge to provide a financial driver for improved sanitation has been shown Africa (Diener, et al., 2014; Murray, et al., 2011; Mallory et al, 2016). Suitability of faecal sludge recycling to generate economic value as a profitable operation depends on the context in terms of local culture and infrastructure, perceptions of waste-based products and availability of competing products. In Malawi, illegal disposal and reuse in agriculture by people in surrounding urban areas are practiced (Chiposa, et al., 2017). Increasing urbanisation and limited

property space in Malawi makes the emptying of pit latrines, the most common form of sanitation facility, an increasing difficulty for households (Chunga, et al., 2016; Chirwa, et al., 2017).

This research, which is part of a wider study of urban reuse of faecal sludge, investigates the issues of equitable access to sanitation and faecal sludge reuse in a city of Malawi, by looking at the implementation of Skyloo facilities and direct reuse of sludge in agriculture, and how well suited they are to people with disabilities and the poorest members of society.

Method

Data Collection

Our case study was conducted in a city in Malawi in 2016 and 2017. The exact location has been withheld from publication since many of the activities reported are illegal. In the study city, there is a central site for disposing faecal sludge managed by the local government that mostly receives waste from formal settlement areas and institutions with septic tanks, carried to the site with a vacuum tanker, however it was closed for rehabilitation during the time of this study. There have also been initiatives from several NGOs to implement composting toilets. Our study was limited to assessing the Skyloo latrine (ecological sanitation) design. In the study area, Skyloos have been introduced to improve household sanitation and provide compost for households that had previously relied on unimproved pit latrines, shared latrines or open defecation (Table 1).

Semi-structured interviews were conducted in three purposely selected urban neighbourhoods of high density population within the city. Interviewees were asked about their sanitation services, awareness and perceptions of services and potential for reuse of faecal sludge in energy or agriculture. Interviews were conducted to look at the existing forms of faecal sludge reuse, including household composting toilets and application of sludge from the central treatment site. Interviews were conducted with users who had composting toilets (n=47) and farmers who applied faecal sludge (n=11) either directly collected or diverted from the disposal site to understand the issues surrounding reuse in urban Malawi. A purposive selection of Skyloo interviewees were chosen from all known projects with a sample of between five and 15 interviewees from each, depending on the number of people each project served and ability to find interviewees by snowball sampling. Skyloo users were asked about how they had been introduced to the technology, how they had financed the purchase of the toilet, and how they found the use of the toilet and compost. Farmers residing adjacent the central treatment site and using untreated sludge in agriculture were selected until the snowball sampling led back to the people who had already either participated or not consented to the research. Farmers who used faecal sludge from the disposal site were asked about how they used it, difficulties with access and how it compared to normal fertiliser.

Data Analysis

Interviews were conducted in the preferred language of the interviewee and transcribed within 24 hours. Photographs were also used to capture individual cases representative of result themes. The interview transcripts were coded thematically using Nvivo 11 according to guidelines set out by Robson and McCartan (2016). One of the major themes that emerged from the data analysis was that of equitable access to both sanitation services and reuse of faecal sludge being insufficient. This aspect of when faecal sludge reuse does not work is explored in the results

Ethical Statement

This research had ethical approval from The University of Edinburgh and the Republic of Malawi National Commission for Science and Technology.

Table 1. Skyloo Projects					
Project	**Financing Approach**	**Material Contributions by User**	**Sensitisation Approach**	**Target User**	**Year of Project Implementation**
1	100% subisidised by donors	No	Presented different options then built technology	Urban families of orphaned children through faith based organisation	2014-15
2	Loan for house and Skyloo combined	No	Provided standard house and sanitation design	Urban poor	2010
3	Loans to households from donor fund for urban development	No	Marketed technology in urban areas and provided loan for construction	Urban residents	2010-2016
4	Loans to households with donor collateral	Bricks and sand and optional further contribution	Marketed technology in urban areas and provided loan for construction	Urban residents	2012
5	Loan for house and Skyloo combined	Mudbrick contributions	Provided standard house and sanitation design	Urban poor without housing	2007-2010

Results

It was clear from the fact that 20 interviewees out of 59 interviewees using Skyloos or applying faecal sludge mentioned issues of limited access to sanitation that current forms of reuse being practiced are not inclusive designs that achieve equitable access to sanitation. This was especially true for donor driven projects aiming to target vulnerable children or people with disabilities. The reuse of faecal sludge from the disposal ponds is physically demanding in terms of transport (walking with a heavy load of sludge carried on the head), making it difficult for people with certain disabilities to be able to access manure for organic fertiliser, with 11/12 farmers interviewed having to transport large weights (50kg+) of sludge manually for use in agriculture:

"*There are accessibility problems especially in rainy season because it's very heavy to carry while in dry season it is easy to access but now more difficult*"
(Farmer Using Sludge)

"*Since I started using I've had high yields for consumption and for sale. I have a 1 acre and a 2 acre farm. Transport is the main issue as I have to carry but if I could transport to here I could maybe use the sludge here also*"
(Farmer Using Sludge)

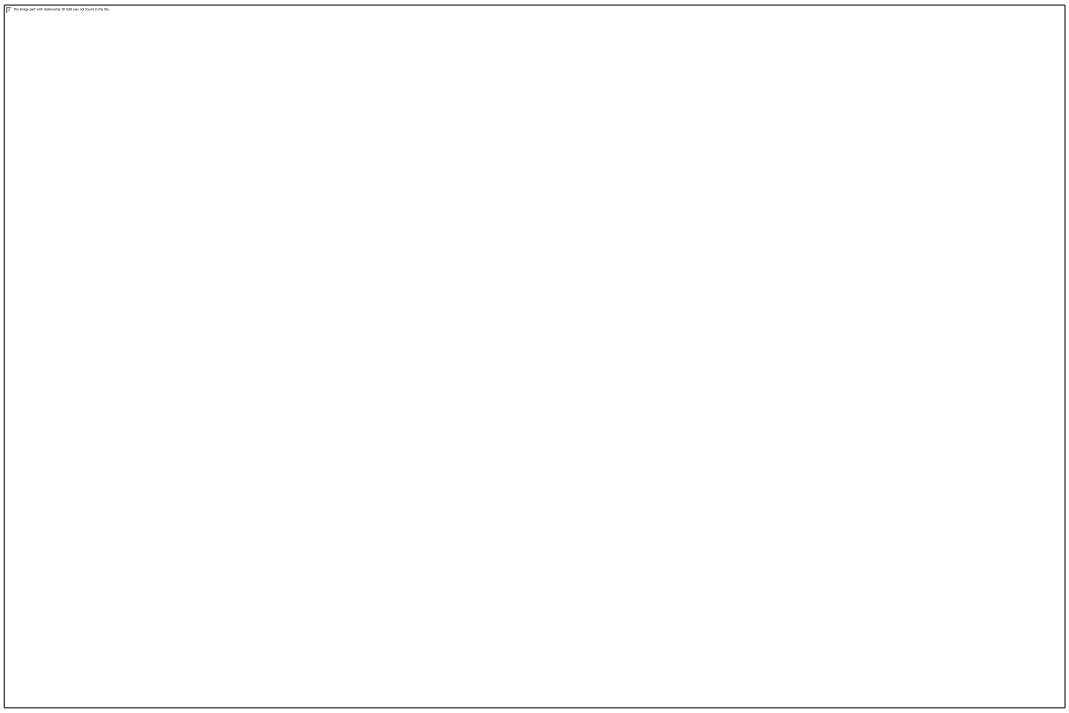
Skyloo toilets also have issues with being an accessible design for physically vulnerable or disabled people and children. 10/48 Skyloo users cited issues of children using the Skyloo correctly, with them often forgetting to add ash or divert urine correctly, and seven users let the children use a pit latrine instead:

"*It's ok but somehow it is difficult to use as with the children they get confused. To me I would prefer a pit latrine*."
(Skyloo User, Project 2, Female, 57)

The issue of physical strength affecting the tools and knowledge to maintain and use Skyloos was particularly prominent in project 1, where the Skyloos were being built for families that often supported many orphaned children and would be considered ultra-poor. Some of the recipients and family members were also suffering from HIV and too poor to afford basic tools for accessing the back of the Skyloo:

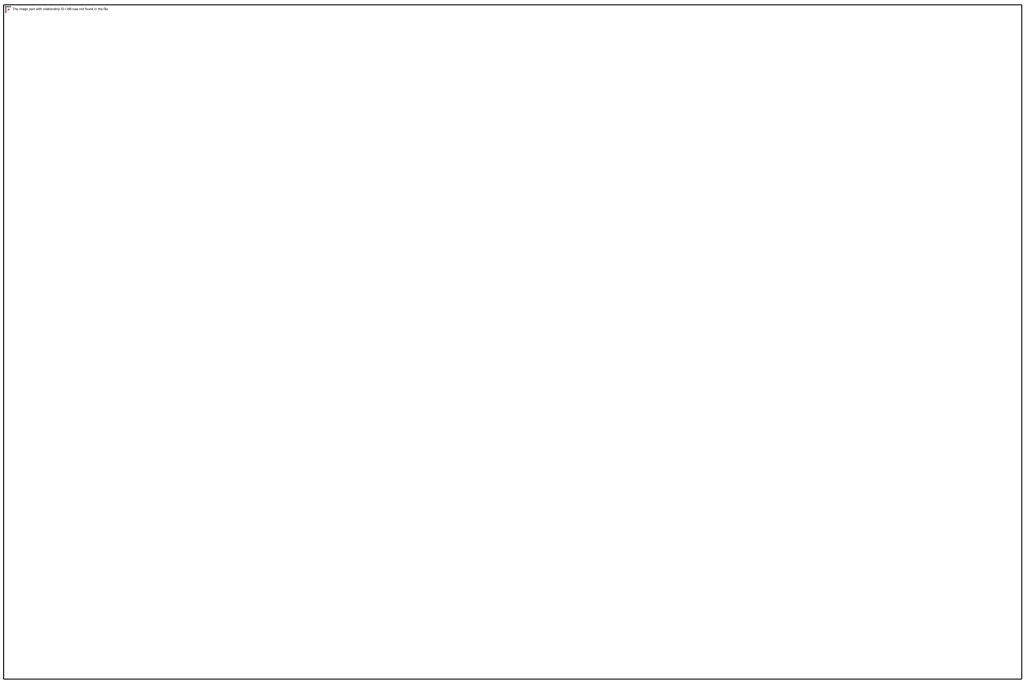
"*For small children and old people though, it (the Skyloo design) is not best. For my mother she fell from the steps once and is still having problems with her knee. But for me there's no problem….. If I see benefits of it I'll use. For now I'll use a pit latrine*."
(Skyloo User, Project 2, Female, 31, Skyloo shown in photograph 1)

"So the concrete in the steps is starting to crack and the stairs are failing so I have had to remove the tree nearby as the roots are causing issues….. *The other issue with harvest is that I am too weak to do it as I have HIV and am elderly so can't open and do it.*"
(Skyloo User, Project 1, Female, 59, Skyloo shown in photograph 2)



Photograph 1. Abandoned Skyloo and latrine used instead (right)

Source: Authors



Photograph 2. Skyloo with tree removed and stairs

Source: Authors

Discussion

Much data was collected during the course of this study; only some of this had bearing on accessibility issues. However, it was clear from all the relevant data that both the domestic composting and the direct application of sludge in agriculture were approaches to reuse that currently fail to serve the most vulnerable members of the population. This suggests that in order to ensure that basic levels of sanitation are achieved among the poorest, the emphasis should be on ease of access rather than reuse due to the physical requirements. The physical demands of maintenance for faecal sludge reuse mean that the methods designed to promote it are currently not working as NGO solutions for the most vulnerable people. For implementing projects targeting people with disability and the poorest populations, the physical and time demands of technological options need to be considered. A handrail option for the Skyloo stairs was observed at one house, which may help to assist some people on a limited basis. While other ecological sanitation designs (non-elevated) could perhaps also be more accessible for users with special needs, below ground surface pits could still be prone to flooding and be labour intensive to empty for reuse.

Conclusion

The potential for improved sanitation and faecal sludge reuse in agriculture either through Ecosan facilities such as Skyloos or direct reuse in agriculture could provide improved livelihoods in urban areas of Malawi when properly designed. Our research found both approaches are currently not suitable for the poorest members of society who are unable to afford basic tools or have time available for maintenance and operation tasks. They are also unsuitable for those with physical disabilities, with Skyloos use of stairs in design leading to difficulties of access and the transport of compost or faecal sludge being too physically intensive. To ensure equitable access to sanitation in urban areas for vulnerable people the design of household sanitation for beneficial reuse has to focus on ease of access and maintenance tasks as a priority. In terms of reuse in agriculture any designs intended to target vulnerable groups in society need to account for transport distances and intense physical requirements.

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